RF CLOSED LOOP CHECKOUT OF THE AGENA VEHICLE

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SUMMARY

On a given missile range, it may be necessary to perform Radio Frequency tests on missiles or space vehicles. If there are many complexes on the launch base, RF transmissions from a complex may interfere with the RF tests on another complex. If RF facilities external to the complex must be used for all RF tests, only one complex at a time may perform RF checkout procedures. A requirement may also exist that dictates all RF transmissions must be secure from reception outside the launch complex.

An RF checkout system must then be designed to meet these requirements. Such a system has been designed by the Lockheed Missiles and Space Company, AGE Division, Van Nuys, California. It is known as the RF Closed Loop System. It was designed to checkout VHF FM/FM telemetry and S-Band tracking and command systems in the Agena Vehicle. The RF Closed Loop System includes complete recording capability for TM Video signal storage and permanent records of all quantities associated with vehicle RF transmissions.

The system is not necessarily limited to monitoring VHF FM/FM telemetry and S-Band tracking and command systems. It may be changed to accommodate any TM or command system by changing the blockhouse monitoring equipment, such as receivers and other demodulating equipment. One limitation is the frequency bandwidth of the long-run transmission lines. The basic concept of non-radiation of RF transmission outside the launch complex until launch and its development into hardware is the main premise of this paper.

INTRODUCTION

A launch base and missile range is usually used by many contractors to checkout, launch and track missiles and space vehicles. One of the most critical types of checkout is that of the Radio Frequency data and Communications equipment in the vehicle. Along with RF checkout of the vehicle equipment, checkout of the RF links between the vehicle, the tracking stations, and the Complex monitoring systems is also accomplished.

When many contractors are performing RF checkout procedures on their various vehicles, conflicts in the use of the launch base and missile range Radio Frequency transmission and receiving facilities are bound to arise.

When RF checkout procedures must be conducted simultaneously with Launch Countdown RF checkout, problems occur in the areas of interference with other RF transmission and in the maintenance of the security of all transmissions until launch time. There may also be a requirement to have simultaneous countdown and launches spaced within short time intervals on the same complexes or on adjacent complexes.

The need then arises to have a system that will perform pre-launch and system RF checkout procedures within a launch complex without interfering with adjacent complexes, tying up launch base and range facilities which may be required for monitoring a launch countdown, and without violating security regulations governing RF transmissions on the particular missile range.

The following pages will describe a self-contained, independent, and complete system which will meet these requirements and which, at the time of this writing, is being installed and checked out at Vandenberg Air Force Base in the Pacific Missile Range on the coast of California. This system was designed to monitor and checkout TLM, and S-Band Command and Tracking Beacon in the Agena "D" Space Vehicle which was designed and built by Lockheed Missiles and Space Company in Sunnyvale, California. The actual design of this checkout system was performed by the Aerospace Ground Equipment (AGE) Division of Lockheed Missiles and Space Company located in Van Nuys, California. The system as described starts with the generation of checkout signals in the Agena and follows these signals in an orderly manner from their routing over the data link cables to their processing and readout. Only a small portion of technical operational details are included in this paper.

LAUNCH BASE DATA LINK OPERATIONS - BEFORE AND AFTER RF CLOSED LOOP CAPABILITY

Prior to closed loop operation (Figure 1a), each launch complex would radiate to a receiving tracking station and a TM Data Processing Center. Since there is usually one receiving tracking station and one TM Data Processing Center, only one complex at a time may use these base facilities when the complex is performing any type of RF checkout procedure. In order for a complex to perform RF checks, it must first receive an RF clearance from the launch base commanding officer. All other launch complexes must stop RF transmission while the one complex is transmitting RF energy.

No TM or any other RF check may be accomplished by any other complex until the one complex has completed its checks. When one complex is performing RF checks the TM Data Processing is being used and no other complex can perform any type of TM checks.

When there is Closed Loop operation (Figure 1b), each complex may perform RF tests independent of every other complex. Each complex has a complete, self-contained RF monitoring and command system with the capability of performing all the necessary RF checks without the use of launch base RF facilities, without interfering with other complexes, and keeping all communications between the complex and the vehicle in a maximum security mode. Each complex will use the launch base RF facilities only during an actual launch countdown while the other launch complexes perform their respective pre-launch and system checks. In addition, closed loop operation provides the ability to ascertain blackbox malfunctions in the vehicle.

GENERAL SYSTEM DESCRIPTION

The system known as the RF Closed Loop Checkout System, which will be described in the following paragraphs, will meet the requirements of (1) non-interference with other launch complexes, (2) non-use of launch base and missile range RF facilities during pre-launch and system testing, and (3) secure RF transmission. The expression "Closed Loop" actually is not defined as the classical servo-mechanism term but implies the non-radiation of RF energy beyond the radiation limits as specified by range regulations.

This system (Figure 2) consists of a Data Link between two complexes with a blockhouse and three pads on each complex. The Data Link between complexes allows for simultaneous countdown of a vehicle on each pad and allows switching from one complex to the other until actual launch time. Each complex has identical equipment to permit checkout of a vehicle on one complex at the blockhouse of the other complex.

DESCRIPTION OF THE COMPLEX AND INTERCOMPLEX DATA LINK (Figure 3)

Each pad is connected to the blockhouse on the complex and complexes are interconnected by solid outer conductor coaxial cable. RF signals in the vehicle are switched from the vehicle antennas to coaxial connectors on the vehicle umbilical connector. The RF signals are multiplexed on the pad to the coaxial cable and fed to the blockhouse. The signals then go to an RF distribution system where they may go to an adjacent complex or to the RF monitoring equipment in the blockhouse. The Open Loop antennas of the data link are also connected to this distribution system.

The long run coaxial cables have a range in length of 1500 to 2500 feet. The diameter will vary depending on the frequency range of the signals which will be carried on the cables. Both ends of the long run cables are terminated in receptacles which provide means for pressurization of the cable. The cables are pressurized with nitrogen gas to guard against the penetration of moist air into the coaxial cable body. Any penetration of moist air into the coaxial cable can seriously affect its transmission characteristics. Each end of the cables have a pressure gauge to monitor the internal gas pressure of the cable.

The RF signals which are transmitted from the vehicle are multiplexed before they are fed to the long run coaxial cables. The multiplexer is located on top of the umbilical mast where the combined signals are connected to the coaxial cable. The cable is routed down the mast to the pad and then routed from the pad to the blockhouse.

BLOCKHOUSE COMMAND AND MONITOR SYSTEM (Figure 4)

The RF signals which originate from the pad and terminate at the blockhouse are either routed to the blockhouse antennas or the data processing equipment in the blockhouse. The type of data processing equipment required will depend upon the type of RF signals which the vehicle generates. For example, if the telemetry is the PCM type and the vehicle has a Doppler tracking beacon then the blockhouse data processing equipment must be capable of handling these types of RF signals. For the purposes of clarity, the blockhouse system which will be described in the following paragraphs has the capability for monitoring VHF FM/FM telemetry (220 - 260 megacycles) and an S-Band (2500 - 3000 megacycles) tracking beacon and command signals.

The blockhouse system is divided into several subsystems. These are (1) RF Distribution, (2) TM Signal Processing, (3) Magnetic Tape Recorder, (4) Indicator and Monitor, and (5) Command and Monitor.

1. RF Distribution Sub-System (Figure 5)

The RF Distribution Sub-system performs two essential functions. The first function is to distribute incoming RF signals from the pad or from the adjacent complex to the monitoring equipment. The second function is to provide a method to check the VHF TM Monitoring System.

The distribution of the incoming RF signals is accomplished in the following manner. The multiplexed RF signal originates from either pad, where the signal goes thru a pad selector switch, or from an alternate complex. It is then routed to an RF patch panel. The signal is patched either to an adjacent complex or to a band separation filter. The output of the filter provides two separate signals, VHF and S-Band.

The VHF signal is patched to a demultiplexer if there is more than one VHF link. The demultiplexer output provides each separate VHF link on the RF patchboard. The VHF is then either routed to the TM Signal Processing Subsystem for data handling, storage and conversion or to the Indicator and Monitor Subsystem for RF power measurement, frequency measurement and spectrum analysis.

The S-Band signal is either routed directly to the Command and Monitor Subsystem where it is given a performance test or to the Indicator and Monitor Subsystem for frequency measurement, RF power measurement and spectrum analysis.

The RF Distribution System also permits the reception of RF signals from the antennas at the blockhouse. The antennas are connected by suitable coaxial cables to the RF patchboard.

The RF Distribution provides, in addition to it's distribution capability, a means of self-checking the VHF TM Signal Processing Subsystem. This capability is provided by simulation of the types of signals which are sent by the vehicle on the TM links.

The vehicle signals are processed by the frequency modulation of these signals on voltage controlled oscillators which correspond to the standard IRIG FM Telemetry Channels. These signals are then frequency modulated again on the main RF carrier frequency.

The simulation of the vehicle signals is accomplished in the RF Distribution Subsystem in a similar manner. The original data signals are obtained from the audio oscillator or the commutator simulator. The audio oscillator is used to generate a single signal ranging in frequency from 1 to 20,000 cycles per second. The commutator simulator is used to simulate non-return-to-zero (NRZ) commutated signals in the vehicle. The Vacuum Tube Voltmeter is provided to calibrate either the Audio oscillator or the Commutator Simulator outputs.

The signals from the Audio Oscillator or the Commutator Simulator are patched on a Video Patch Panel to the Switchable Voltage Controlled Oscillator (SVCO). The SVCO is capable of generating the signal frequency-modulated on an IRIG FM Telemetry Channel. The SVCO can be switched to each of the IRIG channels.

The modulated signal is patched on the Video Patch Panel and frequency-modulated by the VHF Signal Generator on the main RF carrier signal which appears at the RF output of the VHF Signal Generator. The RF output is then connected to the RF Patchboard. The main TM RF Signal is patched in the same manner as the incoming vehicle VHF signals.

2. TM Signal Processing Subsystem (Figure 6)

The TM Signal Processing Subsystem provides the means to process the main TM Carriers into the original signals that occur in the vehicle for recording and direct reading of these signals.

The RF carriers are obtained from the RF Distribution Subsystem and brought to an RF Patch Panel in the TM Signal Processing Subsystem. The RF carriers are patched to VHF Receivers which are tuned to the center frequency of each RF data link. The VHF Receivers demodulate the RF carriers and provide a video signal comprised of all the FM sub-carriers on each link on a video patchboard.

The video signals are patched on the video patchboard to one of several articles of equipment. The video signals may be patched to the Magnetic Tape Recorder Subsystem for recording and storage for later playback. The video signals may also be patched through the switchable Band Pass filter if necessary or directly to each sub-carrier discriminator. If the video waveform must be viewed or examined for any reason, the video signals may also be patched to a Spectrum Analyzer, a 5-inch Oscilloscope or a 17-inch Oscilloscope. The Master Pulse Sync Generator is used for providing synchronization for viewing video signals.

When the Magnetic Tape Recorder Subsystem supplies the video signals, these signals are patched to the Delay Line and Reference Discriminator to compensate for variations between recorder recording and playback speeds. The signals are then routed to the sub-carrier discriminators.

The output of the sub-carrier discriminators are routed to a Signal Patch Board. If the data contained on a sub-carrier is derived from a commutator in the vehicle, the output of the sub-carrier discriminator is patched to a 60 channel Decommutator. The maximum number of commutator points in the vehicle is also sixty. The Decommutator outputs are patched to the Indicator and Monitor Subsystem where the signals are measured, monitored and permanently recorded.

3. Magnetic Tape Recorder Sub-System (Figure 7)

The primary function of the Magnetic Tape Recorder Subsystem is to record and store TM video signals so that they may be processed while the TM Receiving equipment is receiving other TM links. The video signals may then be played back and the signals processed at a later time than the actual transmission of the TM signals.

The Magnetic Tape Recorder Sub-system is capable of recording four channels simultaneously. The recorder can play back one channel at a time. When the recorder is in the record mode, the incoming signals are routed through a device which performs a process called Pre-detection Conversion. This process receives the input video signals and converts their center frequencies to a single center frequency. All the input video signals then have identical center frequencies. This process is necessary because the center frequency of the video signals is usually beyond the frequency response of the recording heads. The converted center frequency is determined by the maximum frequency response of the record and playback heads and the bandwidth of the video input signals. For example, if the maximum frequency response of the record and playback heads is 1.2 megacycles per second and the bandwidth of the video signals is 1 megacycle per second, then the converted center frequency is given as $1.2 - 0.5\ (1) = 0.700$ megacycles per second or 700 Kilocycles per second. Even if the center frequency of the incoming signal is within the maximum frequency response of the recorder heads, the bandwidth of the video signals may be wide enough so that information contained at the extremities of the signal spectrum might be attenuated to such an extent that the data at the spectrum fringes will not appear on the tape.

When the Magnetic Tape Recorder Subsystem is in a playback mode, the signals are played back from the tape one channel at a time and have the converted center frequency on its spectrum. Before the signals are fed back to the TM Signal Processing Subsystem, they must be reconverted to the center frequency which corresponds to the center frequency of the signal outputs of the VHF Receivers. This is accomplished through a set of discriminators or demodulators.

A video patchboard is provided for versatility in the operation of this subsystem.

4. Indicator and Monitor Sub-System (Figure 8)

The primary purpose of the Indicator and Monitor Sub-system is to measure, monitor and record all of the various quantities that are directly related to RF Closed Loop Checkout. Among these are RF and video frequencies, RF power measurement, signal voltages and frequencies and occurrences of significant events. Spectrum analysis is also made available to provide the operator a means of examining signal spectrum structure.

The measurement of frequency is accomplished by one of two methods. Both of these methods use a counter. If the frequency to be measured is less than the frequency range of the counter, then frequency may be measured directly by connection to the input of the counter. If the frequency to be measured is greater than the frequency response of the counter, a transfer oscillator is used in conjunction with the counter. The transfer oscillator uses heterodyning techniques to obtain a frequency difference which is within the frequency response of the counter. The transfer oscillator provides a means for reading the frequency up to 12,000 megacycles with an accuracy of 5 parts in 100 million by reading the harmonics of the basic signal on the transfer oscillator. The synchronizer provides the synchronization of the sampling periods of the counter and transfer oscillator and phase locking between a reference frequency from the counter and IF of the transfer oscillator. The phase error produced by the beating of reference frequency and the transfer oscillator IF is the signal which is monitored by the counter where the frequency is read directly. The counter also provides a binary-coded decimal signal which can be read into a digital recorder for a permanent record of all frequency measurements.

AC and DC voltages are measured by converting the voltage level to a frequency properly scaled so the counter will read the voltage directly. Since the decommutators in the TM Signal Processing Sub-system have sixty outputs, it becomes necessary to scan each of the decommutator outputs at a rate equal to and synchronized with the commutators in the vehicle. The scanner provides a capability of reading a whole group of signals without changing connections. The counter provides BCD data which is recorded on a digital recorder as described above.

For a permanent record of TM signals as to their waveform, frequency and amplitude, two oscillographs are provided with their associated calibration equipment. The oscillographs have a capability of recording signals up to a frequency of five thousand cycles per second. The oscillographs also provide monitoring of signals with respect to time.

The event recorder provides a means of monitoring the occurrence of events with respect to time. Events that occur in the vehicle plus events that occur within the checkout complex, such as commands to the vehicle, are recorded on the event recorder.

5. Command and Monitor Sub-System (Figure 9)

The primary functions of the Command and Monitor Sub-system are to check the vehicle's S-Band tracking beacon and command system, send S-Band Beacon Commands from the blockhouse while the vehicle is on the ground, and monitor the command tracking station by verifying its command through simulation of the vehicle beacon and command system.

The vehicle command system is functionally separated from the vehicle tracking beacons although the commands and beacon interrogation are performed on the same RF carrier. The command system is in the form of time base modulation of two audio tones. As can be seen in Figure 10, the command pulse is placed between the beacon pulses and has a time displacement of T_2 seconds. T_2 will vary when the command is displaced by a time distance of T_3. T_3 is a total time excursion, and the frequency of the displacement of the command pulse is equal to the frequency of the combined audio tones. The vehicle beacon system works in the following manner: two pulses are sent spaced T_1 seconds apart. If T_1 is within the proper values, a transponder sends back a reply pulse on a different frequency from the transmitted pulses. The delay between the coincidence pulse and the transponded reply is measured and desired tracking information is obtained. If the displacement between the leading edges of the address pulse and the command pulse is greater than $T_2 \pm T_3$, the command will not be accepted by the vehicle.

The three pulses are amplitude modulated on the S-Band Carrier as bursts of RF energy. The transponded pulse is processed in the same manner.

The Command and Monitor Sub-system has the capability to operate in one of three modes due to the versatility which is derived from the addition of an RF patchboard.

The first mode of operation is depicted in Figure 11. This mode is used for the checkout of the vehicle command system over the long run coaxial cable. The command modulator generates the pulses at a given repetition rate as shown in Figure 10, including the time base modulation of the command pulse. The pulses from the output of the command modulator are amplitude modulated on the RF carrier through the signal generator and transmitted to the vehicle. The transmitted signals are monitored through a transponder which during the time of the operation acts as a receiver. The transponded pulse out of the transponder will be sufficiently attenuated so that the receiver will not receive it. The transmitted pulses are monitored and viewed on an oscilloscope. The code pulse is routed to a decoder where the pulse is decoded, and the verification indicator monitors what tones and command have been sent. The reply pulse from the vehicle transponder is monitored by a receiver tuned to the frequency of the return pulse and viewed on an oscilloscope.

The second mode of operation is to monitor the tracking station when it is interrogating the vehicle as depicted in Figure 12. The transponder monitors the tracking station signals which are viewed on an oscilloscope. The tracking station commands are decoded in the decoder and displayed on the verification indicator. The tracking station commands can then be monitored to see if the proper pulse spacing and tone modulation are being transmitted by the tracking station.

The third mode of operation in the command and monitor sub-system is a method of checking the operation of the sub-system completely independent of all equipment in the blockhouse. The block diagram for this mode of operation is depicted in Figure 13. Three pulses are formed in the command modulator and amplitude modulated on the transmission carrier in the signal generator. The transponder receives the three pulses, returns the reply pulse on a frequency (receiving frequency) other than the transmission frequency, and sends the code pulse (second pulse) to the decoder. The decoder decodes the code pulse and the verification indicator provides a visual indication as to what command and tones were sent by the command modulator. The receiver, which is tuned to the receiving frequency, receives the reply pulse and demodulates it. The reply pulse and the three transmitted pulses are displayed on the oscilloscope. This procedure satisfies the requirement for a self-check of the command and monitor sub-system.

If there is a requirement to measure the S-Band carrier frequency, power, tone frequencies or pulse repetition rate, the frequency and RF power measuring equipment in the Indicator and Monitor Sub-system can be utilized by suitable sub-system interconnection through RF patchboards.

CONCLUSIONS

The system that has been described in the previous paragraphs is a complete and independent system which will perform all the necessary RF pre-launch and systems checks without the aid of external RF facilities and without interference with other launch complexes. This system will checkout the vehicle VHF telemetry and S-Band tracking and command systems. All of the sub-systems described in the previous paragraphs are designed to checkout Data Links within the frequencies indicated. Frequency limitations are imposed upon this system because of the capability of the receivers used in the system and because of the long run coaxial cables between pad and blockhouse and between complexes. If the frequency range enters the region where wave-guide is required, the long run coaxial cables would attenuate the signals to and from the vehicle to such an extent that receivers in the block-house or the vehicle would not be able to receive.

Another limitation of this system is that it can only monitor and process FM/FM Telemetry. Many missiles and space vehicles use other telemetry systems such as PAM/FM, PCM/FM or PCM/PM. However, this limitation is not a severe one in that the blockhouse TM processing equipment may be changed to accommodate the various TM systems.

A further limitation is that the system can monitor only one type of command system. If the command system should be changed or another system added, the monitoring sub-systems must be changed accordingly.

It should be evident that the system described has limitations, but these may be overcome. The advantage that it has over other RF Checkout Systems is it's flexibility to handle all RF tests without use of base RF facilities and to switch to the use of antennas during actual countdown. Another advantage is that design changes can be made to the system to accommodate vehicle changes without jeopardizing its non-radiating characteristics.

The most important single fact that can be derived from this paper is not of the equipment itself but of the concept of RF Closed Loop Checkout. This concept is not limited to RF Checkout of the Agena vehicle, but may be used for RF Checkout of any missile or space vehicles.

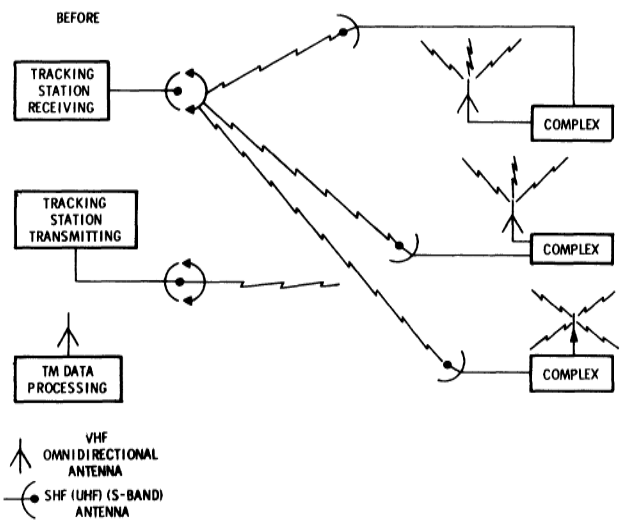

Figure 1a Launch Base RF Data Link Without Closed Loop Capability at the Launch Complexes

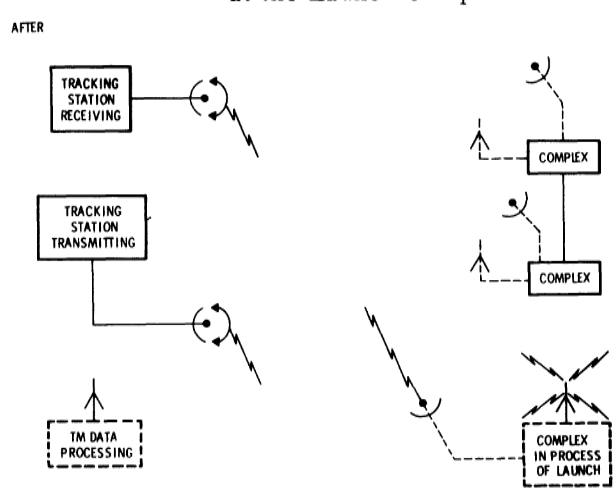

Figure 1b Launch Base RF Data Link With Closed Loop Capability at the Launch Complexes