This paper describes the signal routing and power combining function of the C-band uplink frequency signals in the Galaxy TT&C earth station.

INTRODUCTION

The Galaxy system is the commercial satellite communications system of Hughes Communications Inc. The TT&C earth station is part of this system. Some of the design considerations of the TT&C earth station were the power handling, status and control, mission requirements, simplicity, and cost. The overall system is described, followed by the details of the power combining capability and the trade-offs required for that part of the system.

The Galaxy satellite is a powerful version of the HS 376 communications satellite. Each satellite has the capability of retransmitting twenty-four 36 MHz frequency reuse channels at C-band. The two command and ranging frequencies are located at the two ends of the uplink band and in orthogonal polarizations. The telemetry/ranging frequencies are located at the high end of the downlink band.

Galaxy 1 will be launched on a Delta 3920 rocket in June 1983. It will be dedicated to the distribution of cable television programming, and will relay video signals in the continental United States, Alaska, and Hawaii. Galaxy 2, scheduled for launch in September 1983, will relay video, voice, data, and facsimile communications in the continental United States. An application to the FCC for permission to launch Galaxy 3 is pending.

The Galaxy fact sheet (1) states that “Galaxy has a diameter of 216 cm (85 inches) and is only 277 cm (109 inches) high stowed in the launch vehicle. In orbit, the aft solar panel
deploy, doubling the power output, and the antenna reflector erects for a combined height of 683 cm (269 inches), or the equivalent of a two-story building. The solar array produces 990 watts of dc power beginning of life; two nickel cadmium batteries furnish power during solar eclipse. With a full load of 136 kg (300 pounds) of stationkeeping fuel, Galaxy weighs 519 kg (1,141 pounds) at beginning of life.”

The OCC for the Galaxy system will be located at Hughes Communications Inc. headquarters in El Segundo, California; two remote telemetry and command earth stations are planned, one in Spring Creek, NY and the other in Fillmore, California. Figure 1 depicts the overall Galaxy system. Shown in solid lines are the two Galaxy satellites in orbit, Galaxy 1 at 135 degrees west longitude and Galaxy 2 at 74 degrees west longitude. Spring Creek is the primary T&C station. This is because the uplink beacon required for proper positioning of the spacecraft antenna must originate from the east coast due to spacecraft design. Two ten-meter antennas are located in Spring Creek for steady-state on-orbit operations and are the primary antennas for the uplink beacons, uplink commands, the ranging function, receipt of spacecraft telemetry and some communication uplinks.

Two ten-meter backup antennas are shown at Fillmore, one of them being like those in Spring Creek and the other being a full motion TT&C antenna. The pedestal upon which this antenna is mounted contains uplink and downlink translation equipment, the ATS and the 3.3 kW klystrons. The Galaxy 3 satellite and the three additional limited motion antennas at Spring Creek and Fillmore are shown in dashed lines which indicates the capability for expansion to meet future requirements. The solid lines interconnecting the remote sites with the OCC depict the leased lines used in steady-state on-orbit operations. Dashed lines show the extra lines employed for launch operations for voice communications on the intercom network and for backup of the primary data lines. The solid lines are conditioned telephone lines over which synchronous data at 9600 BPS are passed full duplex between the OCC and remote sites. Dial backup substitution for any failed leased line is part of the system.

The two earth stations are characterized by their antenna types primarily. The four presently planned antennas are identical in size (10 meters). One, at the Fillmore earth station, is capable of tracking launch, insertion and drift orbits and is referred to as the full motion antenna. The other three antennas (2 in New York, 1 in California) are referred to as limited motion antennas and are capable of tracking a geostationary satellite. The equipment strings are hereafter referred to as the limited motion and full motion systems. The details of the RF uplink portion of the full motion system are delineated here. The characteristics of the full motion system are summarized in Table 1. The full motion system is intended firstly to be a tracking station during the launch phase of the Galaxy satellites, secondly to perform on-orbit tests of the satellite, and thirdly as a backup T&C site to any of the limited motion systems. In addition, the Fillmore station was designed to
FIGURE 1. GALAXY OVERVIEW
support different satellite launches. The system is capable of tracking satellites in any linear polarization with the 3700 to 4200 MHz band, and transmitting in any linear polarization between 5725 and 6425 MHz. Furthermore, HPA’s have the capability of phase combining the command uplink to increase the power by theoretically 3 dB. The block diagram of the full motion RF subsystem is shown in Figure 2.

Several points in Figure 2 are labeled ATS and TV Test input. The command and ranging equipment in the antenna pedestal is complemented by several racks of ATS and TV Test equipment for testing the satellite. This equipment will be used to perform acceptance tests on the satellite during drift orbit (approximately 60 days following launch and prior to operation). The 6 kW power combining capability is excluded from the test modes since analysis has shown the uplink EIRP to be adequate for nominal on-orbit operation. The power combining option is intended primarily as a back-up mode to be used during transfer orbit in the event of abnormal circumstances. Testing will be performed on the spacecraft’s communication and T&C systems.

The entire Galaxy ground segment concept intended the remote sites to be unmanned. It is not expected that the full motion system will ever be operated unmanned, but the capability, through the status and control system, is there.

**FULL MOTION UPLINK SWITCHBANK 1**

The full motion uplink switchbank 1 (see Figure 2) is the input interface for all RF signals to be routed through the klystron amplifiers. Those signal inputs include command (primary or redundant), ATS, TV test patterns and HPA tests. The command input is for spacecraft commanding or ranging, the ATS and TV test inputs are for transponder testing, and the HPA test input is for testing the offline HPA. There are three outputs from the switchbank that are connected to the RF inputs of HPA 1, HPA 2, and HPA R. The inputs that are not routed to one of the HPA’s are terminated into 50 ohm type-N loads which are accessible for offline monitoring purposes.

The routing of the command input is through a primary/redundant select switch. The online signal is then split by a 3 dB power divider and one of the paths is routed through a variable phase shifter. These two signal paths are routed to switches that interface with the ATS and TV test inputs and then to the HPA input select switches. The command input can be routed to any HPA for normal commanding or to any combination of two HPAs for power combining (See Figure 2.) The HPA test input is always routed through the offline HPA. The ATS and TV test inputs can be terminated or can be routed to any HPA with a command input routed to another HPA. Alternatively, both ATS and TV test inputs can be routed to any two HPA’s with the command inputs terminated.
FIGURE 2. RF SUBSYSTEM BLOCK DIAGRAM FOR FULL MOTION ANTENNA
The purpose of the phase shifter is to adjust the relative phase of two command signals for power combining. The phase shifter is designed to give a minimum of 360 degrees of phase adjustment at 6 GHz. The phase shifting is accomplished by changing the length of coax internal to the phase shifter. Accuracy and repeatability are maintained by means of a graduated micrometer tuning screw. Status and control of the switchbank interfaces with the status and control unit which is controlled by the status and control computer. Status is displayed and control is achieved via a touch-sensitive CRT. The control of the switches are through latching relays, status for position 1 or position 2 come from a form-C contact closure. The full motion uplink switchbank 1 is a 7 inch (17.8 cm) high standard rack mounted unit.

**3.3 KILOWATT KLYSTRON AMPLIFIERS**

The link characteristics required a minimum EIRP of 86.5 dBW to provide adequate margin during launch and transfer orbit. The gain of the antenna at center frequency is 52.9 dBi. This gain and intermediate losses required that a high power amplifier of output greater than 3 kW be used. It was felt that the power combining option should be implemented in the event of an abnormal launch or for other emergency contingencies. The HPA’s would be used for transponder testing during drift orbit as well as for the uplink command and ranging signals. Some of the driving functions were power output, frequency capability, cost and delivery time.

There were several vendors whose products met these HPA requirements, the final determining factor was cost. The status and control interface of the HPA was designed for the vendor’s own remote status and control panel. We obtained options that were available and interfaced directly with as many controls and statuses as we could, the remaining were conditioned external to the HPA so that they can interface with our status and control unit.

The klystrons have the ability to be tuned to twelve preselected C-band channels. There are twelve communication channels and one command frequency on each polarization. The command frequencies can be accessed via two communication channels. These two channels are common to all three HPA’s, the remaining twenty-two communication channels are distributed as follows:
<table>
<thead>
<tr>
<th>HPA</th>
<th>Command and Communication Channels</th>
<th>Communication Channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1V, 12H</td>
<td>2V, 3V, 4V, 5V, 6V, 7V, 8V, 9V, 10V, 11V</td>
</tr>
<tr>
<td>R</td>
<td>1V, 12H</td>
<td>2V, 6V, 7V, 11V, 12V, 1H, 2H, 5H, 6H, 11H</td>
</tr>
<tr>
<td>2</td>
<td>1V, 12H</td>
<td>2H, 3H, 4H, 5H, 6H, 7H, 8H, 9H, 10H, 11H</td>
</tr>
</tbody>
</table>

H - Horizontal Polarization  
V - Vertical Polarization

The 1V channel is used for communication in the vertical polarization and commanding in the horizontal polarization. The 12H channel is used for communication in the horizontal polarization and commanding in the vertical polarization.

**FULL MOTION UPLINK SWITCHBANK 2**

The full motion uplink switchbank 2 (see Figure 2) is the output interface for the klystron amplifiers. The inputs into the switchbank from HPA 1, HPA 2, and HPA R are WR 137 rectangular waveguide. There are two transmission outputs from this switchbank, one for the horizontal polarization and the other for the vertical polarization. These outputs are connected to the azimuth rotary joint of the full motion antenna. The output of the offline HPA is dissipated into a 4 kW load. A crossguide couple prior to the 4 kW load is the HPA test output. This output is connected to test equipment in the ATS for analysis of the offline HPA’s output signal. There is one other output, it too comes from a crossguide coupler that is prior to a 4 kW load and after a colinear arm of a matched hybrid Tee. This output is for monitoring power due to the adjustment of the phase of one of the inputs to the matched hybrid Tee with the phase shifter in uplink switchbank 1, while power combining. This output is called the power combining null output, because maximum power combining is achieved when this output is at a minimum. The switchbank is designed such that the output of any HPA can be routed to either polarization; or any two HPA’s can be routed to both polarizations; or any two HPA’s can be combined together and routed to either polarization. During initial configuration or while phase adjusting for power combining, the output of all three HPA’s can be dissipated into high power loads. Waveguide terminations can be connected to either or both of the polarizations of the antenna feed when not in use. The output of the matched hybrid Tee is dissipated into an 8 kW load during the adjustment of the phase for power combining. This 8 kW load is comprised of two air cooled 4 kW loads and another matched hybrid Tee which splits the power into the two loads.
While choosing a device for power combining, several other methods were considered. One was a variable power combiner, which was discarded because the isolation of the through ports was insufficient for our requirements. A slot hybrid was considered but we opted for a matched hybrid Tee because its physical characteristics lent itself more readily to be incorporated into the switchbank’s mechanical layout. The configuration of the matched hybrid Tee is of standard design but special materials were used in its construction to handle the 6 kW of RF power traversing its center. Any of the three HPA’s can be input into the E-arm of the matched hybrid Tee, but only HPA 2 or HPA R can be input into the H-arm. The phase adjustment occurs in the signal that goes through HPA 2 or HPA R.

The status and control of uplink switchbank 2 is like that of uplink switchbank 1, except there is an additional control going to the HPA’s. This control inhibits the RF signal in all three HPA’s while switching occurs in uplink switchbank 2. This is to prevent RF power from being reflected into the klystrons. The full motion uplink switchbank 2 is a 16 inch (40.64 cm) high by 69.75 inch (177.2 cm) wide open back unit that is mounted above HPA’s as shown in Figure 3.

SUMMARY

The full motion uplink switchbank 1 routes the command and ranging, TV test, ATS, and HPA test signals to the klystrons with phase shifting capability in one of the command and ranging paths. The klystrons amplify these signals. The full motion uplink switchbank 2 routes these signals to the horizontal and vertical polarization input ports of the TT&C antenna, either directly or through a matched hybrid Tee. Through the use of the phase shifter and the matched hybrid Tee, the output power of any two klystrons can be combined. The TT&C earth station will be configured for switching immediately into the power combined mode during any critical phase of satellite commanding. This switching can be accomplished by the status and control system via the touch-sensitive CRT, without interrupting the uplink commanding computer. The TV test uplink is a test pattern used for cursory testing of transponder operation. The ATS uplink is for the testing of specific parameters of the satellite’s communication system.

ACKNOWLEDGEMENT

Programmatic and operational responsibilities for the Galaxy system are assigned to Hughes Communications, Inc., a subsidiary of Hughes Aircraft Company. The Galaxy satellite and the ground segment are built by Hughes Aircraft Company, Space and Communications Group. Recognition and appreciation is extended to J. Farrell, Program Manager, to D. Garner, Project Manager and to M. Sakamoto, Senior Systems Engineer for their help and encouragement.
REFERENCE

Hughes Aircraft Company, Space and Communications Group, 1981, Galaxy Fact Sheet 816011M-55.

GLOSSARY

ATS          Automated Test System
C-band       4000 to 8000 MHz
EIRP         Effective Isotropic Radiated Power
HPA          High Power Amplifier
HS-376       Hughes satellite with telescoping solar panel and folding antenna with 24 frequency re-use channels at C or K band.
Matched Hybrid Tee Also known as Magic Tee
OCC          Operational Control Center, El Segundo, California
T&C          Telemetry and Command
TT&C         Telemetry, Tracking and Command
WR 137       Rectangular waveguide with inner dimensions of 1.372 inches (3.484 cm) and 0.622 inches (1.580 cm) and frequency range of 5.85 to 8.20 GHz.

TABLE 1
FULL MOTION TT&C EARTH STATION CHARACTERISTICS

<table>
<thead>
<tr>
<th>Frequency:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmit:</td>
<td>5925 to 6425 MHz</td>
</tr>
<tr>
<td>Receive:</td>
<td>3700 to 4200 MHz</td>
</tr>
<tr>
<td>System G/T:</td>
<td>30.1 + 20 log (f/4) dB/K</td>
</tr>
<tr>
<td>System EIRP:</td>
<td></td>
</tr>
<tr>
<td>Combined:</td>
<td>89.0 dBW</td>
</tr>
<tr>
<td>Non-combined:</td>
<td>86.5 dBW</td>
</tr>
</tbody>
</table>

Antenna:

| Size:               | 10 meters           |
| Velocity (AZ & EL): | 1.0 degree/sec      |
| Travel:             | ±165° AZ            |
|                     | +5° to + 90° EL     |
FIGURE 3. UPLINK SWITCHBANK 2 ON 3 HPA CABINETS