Ensuring High Performance Uplink Control and Site Switching With A Monitor and Control System

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Abstract **—Satellite uplink facilities must deliver reliable, uninterrupted service continuity. Broadcasters derive revenue from advertisers that is dependent upon reliable distribution of content. Any interruption in the distribution process results in loss of revenue and market share. Therefore, facility designs include several layers of redundancy; including redundant satellites, backup sites, and backup hardware at each site. An important requirement in design and operation of redundant facilities is the monitoring and control (M&C) of each facility's equipment. In addition to monitoring the equipment at the site, another important M&C role is to monitor uplink conditions, make adjustments to the uplinks, and automate switching of uplinks from the primary to a backup site. Some applications, such as direct-to-home (DTH) stretch or exceed the capability of hardware solutions requiring less expensive and higher-performing solutions: applications particularly well suited for a custom M&C software solution.**

This paper describes the measurement techniques, the challenges, and the M&C solution that was designed to provide a reliable solution for a DTH provider with facilities in Florida, where weather disturbance was considerable and frequent power changes and distribution switching to the backup site were required. The lessons learned and performance achieved can significantly positively impact system costs if considered during the system design.

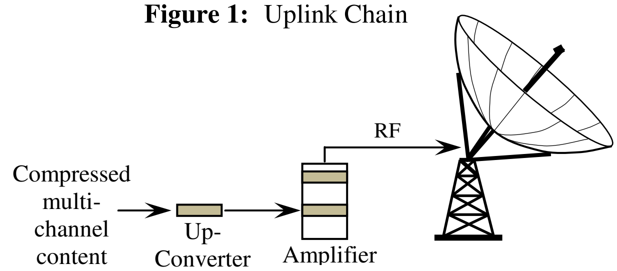
Index Terms—**Attenuation, monitor and control, rain-fade, redundancy site diversity switch, switching, RF attenuation, uplink power control.**

I. INTRODUCTION

Direct-to-home (DTH) distribution means that hundreds of channels of television content are collected at a single site, compressed, and transmitted (an uplink) by radio frequency (RF) to one or more satellites (see Figure 1).

The equipment in an uplink chain consists of an up converter, a high power amplifier (HPA), and an antenna. Each uplink chain is fed a compressed package of television channels which the chain converts to RF and transmission. This RF signal, called a carrier, is transmitted to a satellite that is orbiting the earth in a fixed location. The satellite receives the carrier through one of its many transponders (the satellites in this case had 12) and sends it back to earth (the "downlink") where it can be received through any number of satellite receiving antennas (usually at the home).

Figure 1: Uplink Chain



Large facilities support several uplink chains (this case had thirty at each site); with each an aggregate of dozens of channels. En-route to the satellite the uplink transmission can be degraded. This degradation, or attenuation, is usually caused by rain and/or cloud cover. DTH facilities often distribute hundreds of channels, such as the one described in this paper, such attenuation can create serious disruptions in viewership over large areas. DTH providers strive to minimize program interruptions. However, in order to do so, signal diagnosis and corrective actions to avoid degrading conditions often must be executed in fractions of a second; thus rendering a manual solution untenable.

System design must also consider other factors that can affect uplink transmission, including:

- Uplink attenuation at a site
- Failure of an uplink chain
- Scheduled uplink chain maintenance
- Scheduled antenna maintenance

To mitigate loss of signal and the accompanying loss of revenue, DTH providers build multiple sites. This is done to transfer the primary uplink signal to another backup distribution site when uplink degradation is too great or while repairs or maintenance is carried out at the main site. Uplink chain failure usually is managed intra-site; however, as the software solution in this case matured it became the preferred means to switch a failed chain to the backup site.

An automated site switching solution is intended to provide a broadcast operation the ability to maintain uplink integrity and delivery continuity through monitor and control ("M&C") in the event of:

- uplink attenuation at a site;
- uplink attenuation for a satellite;
- failure of an uplink chain;
- uplink chain maintenance; or
- antenna maintenance

During such events, the broadcast uplink is quickly and automatically transferred by the M&C to a backup site. When negative conditions triggering a transfer are addressed or otherwise cease to exist, the primary site may be returned to its normal operational state.

Finally, costs are an important factor. An ideal solution minimizes cost in several areas:

- Capital: by reducing the engineering design and hardware costs
- Operator costs: by automating as much as possible to minimize head-count
- Operator costs: by simplifying the use of systems through simple and easy-to-understand and act-on user interfaces ("UI"s)
- Maintenance costs of uplink hardware by designing equipment that may be removed from service without service interruption for routine maintenance
- Amplifier energy costs which consume considerable power in transmitting hundreds of miles to the satellite

Crystal Solutions has created an automated site switching solution based upon a M&C system to maintain uplink integrity and delivery continuity by quickly and automatically transferring the uplink to a backup site.

II. Design Requirements

Sky Latin America is an example of the earliest and most frequently used implementation of site diversity switching controlled by a Crystal M&C system. Sky Latin America maintains two uplink sites in Miami Lakes and Port St. Lucie, FL. Both sites were built with 1:6 uplink redundancy. Each site was designed to be fitted with 30 active uplink chains delivering content to 30 transponders on two different satellites. The M&C solution design was required to include:

- The automated site switching solution had to be able to provide both manual and automatic switching:
- by uplink chain or transponder;
- by satellite (i.e. all chains up-linking to a single satellite must switch on a single command); and
- by uplink RF room (a set of 6 or 12 uplink chains)
- Automatic Uplink Power Control ("AUPC") by the M&C was required at each site and independently configured and tested for each transponder.
- Effective isotropic radiated power ("EIRP") measurement and monitoring was required for each uplink chain.
- Since uplink path attenuation is different for each site and for each of the two satellites. This meant that both the switching and AUPC logic must be configured and validated accordingly.
- The M&C graphic user interface ("GUI") must be easy to understand and act on under tense operating conditions
- The solution must be resilient; able to manage site switches occurring over a dozen times daily.
- During site switching, service interruption must be less than a freeze-frame for 2 seconds.
- Transponder switching must be staggered (i.e. must not switch more than one transponder at a time) in order to minimize the impact of the satellite's automated power control.

III. Crystal's Solution Set

Crystal's M&C switching solution outlined below exceeded Sky Latin America's requirements without altering any of the core modules or device drivers.

Performance highlights include:

- Reliable site switching that minimized RF anomalies at the affected satellite; no dual illuminations and RF losses of 5 to 10 msec.
- Consistent power levels on adjacent transponders were achieved by reducing RF disturbance and by managing switch timing to reduce the satellite on-board power perturbation.
- Recovery from uplink chain failures were achieved within 1 second.
- M&C allow unrestricted ability to switch uplinks between sites repeatedly
- Programming interruption was much faster than thought possible and impact was limited to an occasional audio "pop"

IV. Analysis

The entire site redundancy and uplink power control solution was managed by Crystal's M&C system.

Uplink Attenuation Measurement

For reference source redundancy, Crystal uses:

- Radiometers
- A radiometer with a beacon receiver; or
- Beacon receivers

If the budget allows, Crystal's preferred means of monitoring uplink attenuation is a radiometer due to the advantages this solution provides:

- Better accuracy at uplink frequencies; the loss at a beacon signal frequency has to be converted to a different loss value at the uplink frequencies
- Since signal deterioration is thought of in attenuation (in units of dB) which is the unit a radiometer reports attenuation, the use is simple and more intuitive to comprehend than the output of a beacon receiver (usually reported in voltage and then converted to dB)
- For the same reason detailed above, the beacon receiver always demands attenuation be calculated; and this calculation can be unique to the beacon receiver in use (introducing potential for error in the event hardware is replaced, sent out for repair, etc…)
- False switching resulting from sun outages may be avoided since these units consider geographical location, look angle, and time
- Radiometer output is independent of antenna pointing angles thus eliminating the prospect of even modest satellite or antenna positioning changes which may effect a beacon receiver

In this application, four radiometers were used between the two sites; a dedicated unit for each satellite at each site.

Beacon receivers were used as backups for the radiometers and testing was performed to validate performance in each system for both the radiometer and beacon receiver.

Uplink Attenuation Monitoring

Attenuation is monitored at each transmission site and for each satellite. If attenuation was detected at both sites then Crystal dynamically selected the best site for uplink based on each site's attenuation readings.

Automated Site Switching Logic

When attenuation at the primary site reaches user-defined levels Crystal's M&C system:

- Issues an audible and visual warning that a switch may be necessary
- Increases power to the HPA's at the offline facility
- Activates AUPC for the HPA's at the offline facility
- Continues to monitor the attenuation level at both sites

When attenuation breaches a second level user-defined threshold, a transmission transfer takes place for each uplink chain that has an available peer uplink at the diverse site. An uplink chain is considered not available if it is in maintenance or has an active alarm condition. The switch-back algorithm is similar: manually returned or automatically reset.

Crystal's solution for uplink chain switching is considerably different from conventional switching (bringing the backup unit online by tuning the backup amplifier to the proper channel, increasing power and opening a waveguide switch). The result is that service interruption was significantly reduced from seconds to between 5 and 10 msec. The uplink chain switching sequence is:

- Mute the up-converter at off-line site
- Increase power to the off-line amplifier
- Position the waveguide switch at the offline site to place the amplifier on-air
- Mute the up-converter at the online site (at this point transmission is interrupted)
- Wait 0 or 5 milliseconds depending on whether the transmission is moving to or from the primary site (this is necessary to account for the time it takes to transmit the command from the primary site to the backup site)
- Un-mute the up-converter at what is now the online site (transmission is now transferred)
- Position the waveguide switch at what is now the offline site to place the amplifier off-air
- Un-mute the up-converter at the off-line site
- Reduce power at the now offline amplifier

This solution performed so well that the 1:6 redundancy in place for an uplink chain failure was changed such that, instead of transferring the service to the backup chain within the facility, it was instead transferred to the alternate site. This new fail-over scheme was much faster and, had this been known during site design, the 1:6 redundancy controllers and the backup chain for each set of uplinks could have been removed from the system entirely. The capital savings for this solution would have been over $500,000.

Return-to-primary

The same sequence is followed when returning operation from the backup to the primary site. In many circumstances, steps 3, 4, 5 are often reversed: the reversal depends on a logical analysis of the backup-site's equipment and meteorological conditions which were monitored by Crystal.

Manage Satellite Power Management

Switching of uplink on all transponders on a single satellite simultaneously posed unnecessary risk of damage or perturbation on the satellite's on-board automatic power control systems. This risk was abated by switching transponders on a single satellite sequentially and with an inter-switch time of approximately 2 seconds.

User Interface

Given the frequency of site-to-site uplink transfers, a key consideration was to deliver an at-a-glance UI that would allow the user to quickly identify uplink condition across all 30 uplinks. Furthermore, operators must be able to disable auto-transfer (e.g. when an uplink chain was out of service, under maintenance), switch all uplinks common:

- To a single transponder
- To a single satellite, or
- To a single uplink room

Graphic User Interface Solution

Crystal's GUI solution was developed to create the most intuitive at-a-glance perspective as possible. The solution was designed as described in Figure 2 below.

Key user interface features:

1. Services are arranged by satellite and are easy –to -understand
2. With one button selection, services can be transferred for an entire room or satellite from one site to the other
3. Services are vertically arranged by location
4. Large oval indicates service is up from that site while the smaller circles indicate that the backup site is in a condition ready to accept the duty. Circles would turn yellow or red depending on the level of preparedness and/or active alarms
5. This column of buttons allowed uplink systems to be temporarily removed from the automatic switching solution (e.g. maintenance on individual uplink chain, maintenance on an antenna used for a single satellite) by chain, or the entire satellite
6. These fields provide real-time radiometer readings in dB of attenuation

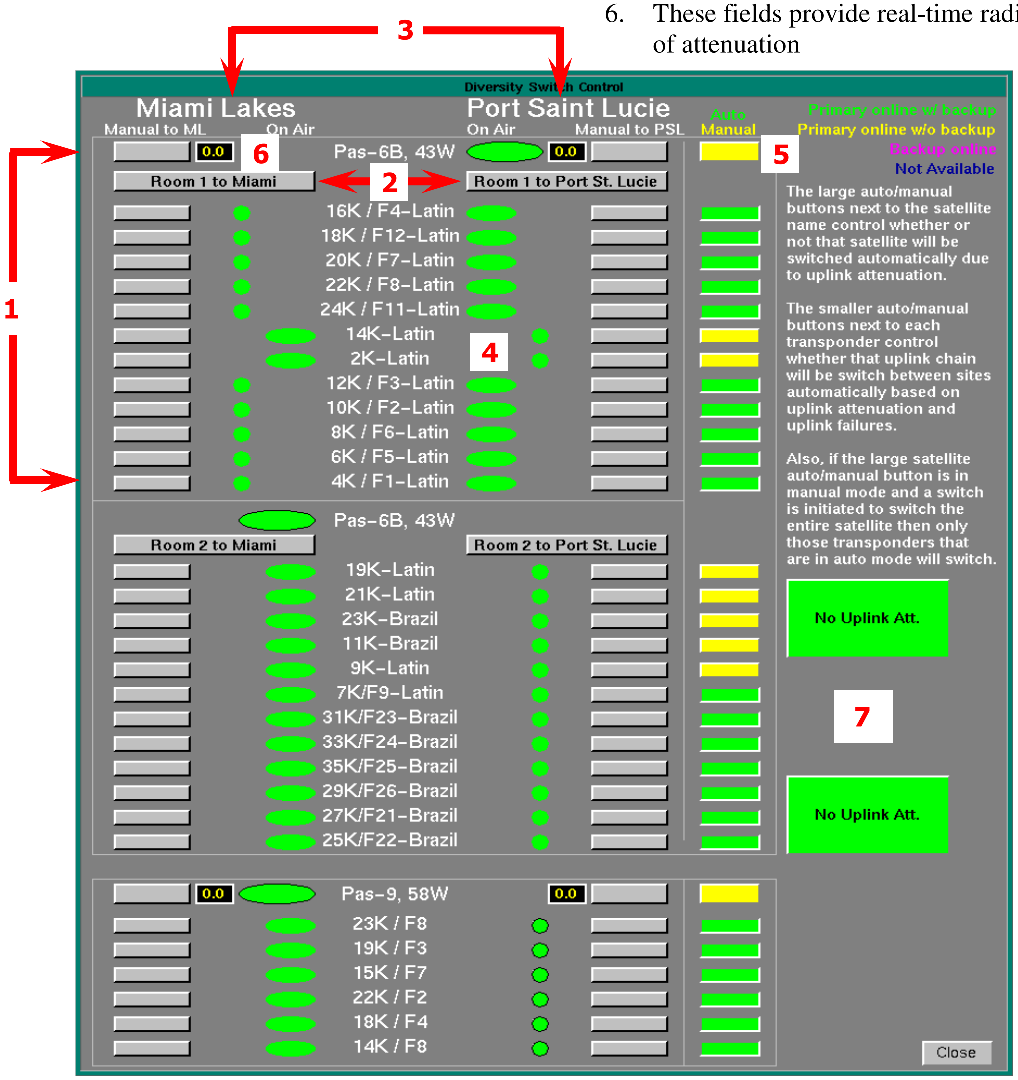


Figure 2: Site Diversity Switching User Interface

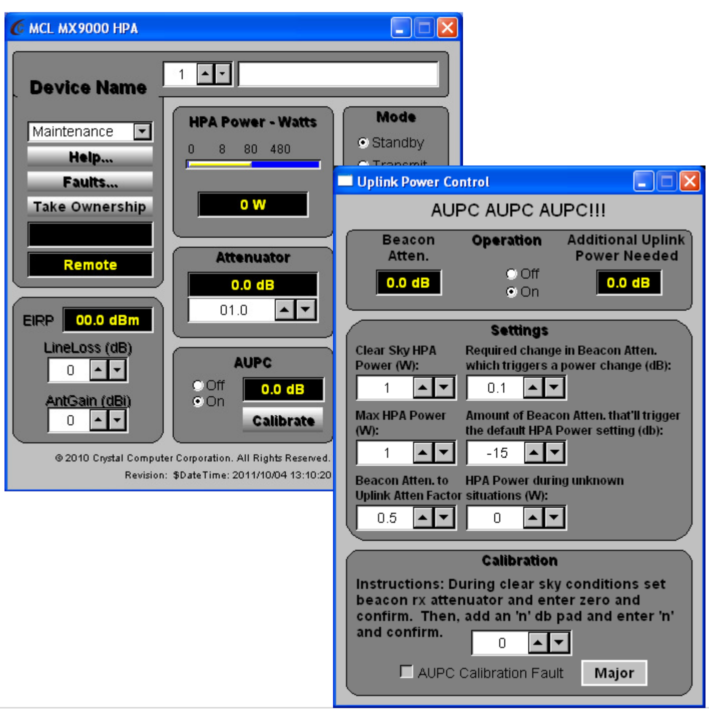
7. These indicators communicated the state of the automation condition. One button was dedicated for each site. These worked as follows:
    a. a **Green** text field (as shown) indicated no atmospheric attenuation and no action was active or pending
    b. a **Yellow** text field indicated attenuation was manifest and HPA's were in a "ready-to-accept" mode; meaning that they were powered up and ready for content shift and un-muting of the up converter.
    c. a **Red** text field indicated attenuation had breached an acceptable threshold

AUPC and EIRP

Crystal provided an exclusive software solution for both EIRP and AUPC on all 60 uplink chains. Furthermore, as attenuation conditions cleared, the offline uplink chain was placed into a minimal power-consuming operational state: this state maintained the offline chain in a ready condition should the online chain fail.

Crystal's EIRP and AUPC solutions are managed and configured through each HPA's M&C interface as shown in these screen shots. The interface on the left is a typical Crystal HPA interface. Note the EIRP section on the left side of the screen. AUPC control, calibration, and attenuation are shown in the center bottom. User selection of the Calibrate button launches the second Uplink Power Control screen shown here.

AUPC setup and calibration is highly flexible. Its out-of-the-box configuration satisfied Sky Latin America's needs and met or exceeded user performance requirements.



V. Solution Results and Performance

The Crystal M&C switching solution exceeded Sky Latin America's requirements and expectations. Crystal was able to create a solution without altering any of the core modules or device drivers. All design requirements were met and some requirements were exceeded including:

- Reliable site switching that minimized RF anomalies at the affected satellite; with no dual illuminations and RF losses limited to 5 to 10 msec.
- Consistent power levels on adjacent transponders were achieved by reducing RF disturbance and by managing switch timing to reduce the satellite on-board power perturbation.
- Recovery from uplink chain failures were achieved within 1 second.
- M&C allowed unrestricted ability to switch uplinks between sites repeatedly
- Programming interruption was much faster than thought possible and impact was limited to an occasional audio "pop"

In addition, during system testing many discoveries led to a more resilient and high-performance application. These included:

- By activating the backup site HPAs with up-converters muted, un-muting the up-converter as content was switched allowed RF interruption to be reliably less than 5 msec. This limited programming impact to an occasional audio "pop".
- Because of (1) above, the Crystal solution was able to execute switching faster than the HPA hardware redundancy controllers. Backup HPAs required a channel changer so that the HPA could be tuned to the correct frequency for the uplink being performed. When the system was set to fail to the 1:6 backup chain the tuning process on the channel changer could take up to 30 seconds. Since there was an HPA at the diverse site pre-tuned to the correct channel, it was significantly faster to transfer service for a failed HPA to the diverse site than to wait for the local backup HPA to change channels. Therefore, in future system designs, uplink chain count can be reduced by 15% and redundancy controllers eliminated.

Crystal's M&C solution positively impacted preventive and reactive maintenance on the uplink equipment: confidence in the system meant that a conditioning of diminishing concern for removal of chains from service.

A result of the successful switching capability of the solution was that the system enabled switches to occur at any time of the day, which became the standard operating procedure of Sky Latin America. The system was configured with appropriate rain-fade thresholds authorizing a dozen or more site switches per day during the heavy-rain season of south Florida.

VI. CONCLUSIONS

Crystal Solutions provided a resilient and exceptionally flexible solution for Sky Latin America using software logic for all aspects of the Automatic Uplink Power Control and Site Diversity needs. Furthermore, this solution was far more flexible than any hardware-based solution available today. With the discovery of the M&C solution for uplink chain fail-over, hardware redundancy controllers can be removed and the fail-to chain eliminated from the system design with little increase in risk. As a consequence, and particularly for all but the most elementary automation examples, software solutions such as the Crystal solution can provide more flexible capability at a lower cost and higher performance than alternatives.

Given real-world knowledge and experience from the Sky Latin America Site Diversity system the design of diversity sites can be simplified. Furthermore, significant cost savings can be realized over the traditional model of simply replicating a single site that has normal redundant capability.

Finally, with proper error correction mechanisms, the viewer experience of site switching for video networks can be greatly enhanced by avoiding network-wide outages due to atmospheric attenuation and equipment failure.

About the Author

Roger Franklin is the President and Chief Executive Officer of Crystal Solutions (formerly Crystal Computer Corporation) of Buford, GA. He is the principle design architect of Crystal's monitor and control solution platform and has worked in the satellite communications industry and with the company since it's inception in 1986. He holds a B.S. in Mathematics from the Georgia Institute of Technology.