Technical Specifications for Satellite Uplink Stations and Test Methods for High-Power Amplifier Systems (Postprint)

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Abstract

The operational stability of uplink station systems exerts significant influence on overall satellite transmission systems. This paper presents an overview of digital satellite uplink stations and the technical parameters of system video and audio channels, alongside testing methodologies for high-power amplifier performance metrics—including output power gain, frequency response, output spectrum, spurious output, third-order intermodulation, and phase noise—employing test instrumentation such as signal generators, spectrum analyzers, and microwave power meters, thereby enhancing our technical capabilities in system parameter detection and maintenance.

Full Text

Preamble

Technical Specifications of Satellite Uplink Stations and Testing Methods for High-Power Amplifier Systems

Abstract: The operational stability of uplink station systems has a significant impact on the entire satellite transmission system. This paper describes the general architecture of digital satellite uplink stations and the technical parameters of audio/video channels, and presents testing methods for key high-power amplifier (HPA) indicators—including output power gain, frequency response, output spectrum, spurious output, third-order intermodulation, and phase noise—using instruments such as signal generators, spectrum analyzers, and microwave power meters, aiming to improve our capability in technical indicator detection and system maintenance.

Keywords: audio/video; satellite uplink system; RF high-power amplifier; technical specifications

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Currently, both central and provincial radio and television systems in China have established digital satellite uplink stations, which shoulder the important task of transmitting and relaying central and provincial satellite broadcast signals. For radio and television satellite uplink stations, safe broadcasting is the primary mission. In digital satellite uplink systems, the program transmission system and satellite uplink system are critical links for ensuring signal quality. Due to continuous uninterrupted operation, the probability of failure is relatively high, requiring regular technical indicator measurements to check system operating status, identify existing problems, and ensure secure and high-quality information transmission.

1. Composition of Digital Satellite Television Uplink Stations

Digital satellite television uplink stations mainly consist of program transmission systems, uplink systems, antenna feed systems, control systems, monitoring network management systems, and power distribution systems. The uplink system is primarily composed of optical receivers, encoders, multiplexers, and RF high-power amplifier systems, as shown in [Figure 1: see original paper]. The workflow of digital satellite television uplink systems is as follows: The digital television signal (SDI signal) from the broadcast center is transmitted via optical transmitter through fiber optic cable to the uplink station (generally with multiple paths). The optical receiver at the uplink station receives the SDI signals from various paths, distributes, amplifies, and automatically switches them before sending to the encoder. The encoder compresses and encodes the digital audio/video signals according to the MPEG-2 format. The encoded signal then enters the multiplexer together with other data signals such as additional audio broadcast data (the broadcast signal follows the same process as the television signal; the optical receiver receives AES digital audio broadcast signals and sends them to the multiplexer separately) to generate baseband signals. The modulator converts the multiplexer output into a 70MHz intermediate frequency signal (using modulation methods such as QPSK, 8PSK, 16APSK, or 32APSK depending on specific requirements). The upconverter then converts the IF signal to the uplink frequency specified by the satellite transponder and amplifies it appropriately to provide excitation for the HPA, which amplifies the uplink RF signal to the rated value for transmission through waveguide to the antenna.

2. Main Technical Specification Requirements for Digital Satellite Uplink Systems

Comprehensively and accurately assessing the technical status of digital satellite uplink systems is challenging. In practice, we primarily evaluate equipment performance and operating status by testing key technical indicators. The following sections elaborate on the main technical specification requirements and partial testing methods for digital satellite uplink station systems.

2.1 Program Transmission System

For fiber optic lines and audio/video channels in the program transmission system, key technical indicators include: average fiber line attenuation (single-mode, 1550nm wavelength), optical receiver sensitivity and minimum overload optical power, standard-definition and high-definition video output interface characteristics (optical receiver output interface, video distribution interface, etc.), and digital audio interface characteristics. Relevant technical standards for fiber optic lines include GY/T 130-1998 "Technical Specifications for Cable Television Fiber Optic Network Access" and GY/T 239-2009 "Operation and Maintenance Regulations for Radio and Television Fiber Optic Transmission Backbone Networks." The average attenuation of fiber lines (1550nm) should be $ $0.25dB/km, while optical receiver sensitivity and minimum overload optical power requirements vary depending on the optical equipment and interface types.

Technical standards for SD/HD video output interface characteristics include GY/T 243-2010 "Technical Requirements and Measurement Methods for Standard-Definition Television Digital Video Channels" and GY/T 157-2000 "Studio High-Definition Television Digital Video Signal Interface," with specific requirements shown in . Digital audio interface characteristic testing can refer to GY/T 182-2002 "Operation and Maintenance Regulations for Satellite Digital Radio and Television Earth Stations," which specifies jitter requirements of <0.07(UI) and audio amplitude peak-to-peak values (across 110Ω resistor) between 2-7V. Since each stage of digital circuits may contain timebase correction systems that can rectify unqualified indicators from previous stages, interface characteristic testing must be performed at every circuit level in digital system detection.

2.2 Encoders and Multiplexers in Uplink System

For encoders and multiplexers in the uplink system, key technical indicators include: encoder ASI output interface, multiplexer ASI output interface, and digital television multiplexer ASI input interface specifications. Reference technical standards include GY/T 212-2005 "Technical Requirements and Measurement Methods for Standard-Definition Digital Television Encoders and Decoders" and GY/T 226-2007 "Technical Requirements and Measurement Methods for Digital Television Multiplexers," with specific requirements shown in ~.

Encoder and multiplexer ASI output interface technical indicators: output amplitude 800$±$80mV, rise time (20%-80%) $ $1200ps, fall time (20%-80%) $ $1200ps, deterministic jitter $ $10%. Multiplexer ASI input interface technical indicators: maximum input voltage $ $880mV, minimum receiving sensitivity $ $200mV.

2.3 RF High-Power Amplifier in Uplink System

For RF high-power amplifier systems, relevant technical standards refer to the acceptance test reports for satellite earth stations from the State Administration of Press, Publication, Radio, Film and Television. Key technical indicators include: output power (gain variation and power stability), frequency response (in-band flatness), output spectrum (bandwidth), in-band and out-of-band spurious signals, third-order intermodulation, and phase noise, as shown in .

3. Testing Methods for Main Technical Indicators of RF High-Power Amplifier Systems

Given the numerous uplink station system indicators and the relative vulnerability of the RF high-power amplifier system in the entire uplink chain, this paper focuses on elaborating the testing methods for HPA system indicators. The testing employs instruments including signal generators (10MHz-1GHz), spectrum analyzers (C-band or Ku-band), waveguide couplers with approximately 50dB attenuation, and microwave power meters. The following sections analyze and introduce the main indicator testing methods.

3.1 Output Power Gain (and Power Instability)

Output power gain refers to the power gain of the HPA, while power instability refers to the variation of actual HPA gain over time (continuously for 1 hour or 24 hours). The power output instability is defined as the ratio of the difference between maximum and minimum output power values to the nominal output power.

Output power gain is typically measured directly. During testing, the signal generator outputs a known power level (P0) as the HPA input signal. An appropriately calibrated directional coupler (with attenuation G0) is connected between the HPA output port and the load, with the coupler output connected to a power meter (measuring power P1). The HPA output power gain is calculated as G = P1 - P0 + G0. The test setup is shown in [Figure 2: see original paper].

Specific measurement steps: First connect the test equipment, turn off the signal generator RF output, adjust the input excitation to minimum (HPA gain maximum), set the signal generator operating frequency to the uplink center frequency, turn on the signal generator RF output, gradually increase the excitation level until the HPA output reaches rated power, measure the coupler output signal power, and calculate the HPA output power gain.

3.2 Frequency Response (In-Band Flatness)

HPA frequency response represents the amplitude-frequency characteristics within the operating frequency band centered on the transmission carrier, reflecting the flatness of the transmitted signal spectrum characteristics, which affects the received signal carrier-to-noise ratio (C/N). The requirement for in-band flatness is 0.5dB p-p for single-channel per-carrier transmission (SCPC) and 1dB p-p for multiple-channel per-carrier transmission (MCPC).

Frequency response is tested using a combination of spectrum analyzer and sweep frequency signal generator. The sweep signal source is connected to the upconverter, with an appropriately calibrated directional coupler connected between the HPA output port and load, and the coupler output connected to the spectrum analyzer. Figure 3: see original paper shows the frequency response test block diagram, while Figure 3: see original paper displays the test interface where the spectrum analyzer shows a smooth amplitude-frequency characteristic curve with amplitude/frequency response variation <0.23dB within 6.67MHz bandwidth.

3.3 Output Spectrum

The output spectrum of the uplink system's RF modulated signal primarily reflects the occupied bandwidth and cosine roll-off rate of the satellite system transmission signal, represented by -3dB bandwidth and -30dB bandwidth (-3dB bandwidth is approximately equivalent to the transmission signal symbol rate, while -30dB bandwidth is approximately 1.20-1.35 times the -3dB bandwidth). Insufficient transmission bandwidth affects the received signal C/N, and asymmetric spectrum shape indicates nonlinear distortion in the uplink system. [Figure 4: see original paper] shows the output spectrum test block diagram, while [Figure 5: see original paper] shows the test interface displaying -3dB bandwidth of approximately 6.87MHz (Marker1-Marker1R) and -30dB bandwidth of approximately 9.5MHz (Marker2-Marker2R).

3.4 Spurious Output

Spurious output from the RF high-power amplifier system refers to unwanted radiation signals in the HPA output besides the main carrier, divided into in-band spurious and out-of-band spurious signals. In-band spurious refers to spurious signals within the uplink signal band, which can interfere with the modulated signal if excessive. Out-of-band spurious refers to spurious signals outside the uplink signal band but within the satellite transponder channel, which can interfere with other carrier signals. Obviously, spurious signals should be sufficiently small compared to the carrier signal.

The spurious testing method involves changing the modulator output to unmodulated single-carrier output, sending the HPA RF carrier signal through a coupler with attenuation to the spectrum analyzer, reading the maximum unwanted radiation signal level (including harmonics) within the specified band besides the carrier frequency, and calculating the ratio of this level to the carrier level as the spurious output. The test block diagram is identical to the output spectrum test block diagram shown in [Figure 4: see original paper]. Test result interfaces are shown in Figure 6: see original paper for in-band spurious, displaying a larger spurious point at -65.3dB (2.38MHz from main carrier), and Figure 6: see original paper for out-of-band spurious, showing a larger spurious point at -66dB (19.83MHz from main carrier).

3.5 Third-Order Intermodulation

When two or more carrier frequency signals are input to the RF high-power amplifier, due to the nonlinear characteristics of the RF HPA, the output produces not only carrier signals but also intermodulation products (2F1-F2, 2F2-F1). Among them, third-order intermodulation products often fall within the HPA operating region, having the greatest impact on the amplifier and reflecting the severity of nonlinearity in the RF HPA system operating region.

Testing involves sending the unmodulated IF carrier signal (70MHz) from the modulator and a single-frequency signal with the same level but approximately 5MHz frequency difference through a mixer to the upconverter, then testing at the HPA output. The difference between the maximum intermodulation level and output carrier level is the third-order intermodulation. The two input carrier levels should be 3dB lower than the single rated input carrier level. The third-order intermodulation test block diagram is shown in [Figure 7: see original paper], with test results shown in [Figure 8: see original paper]. The two smaller single-frequency waves on the left and right are third-order intermodulation products generated after the two single-frequency carriers pass through the RF HPA system, with the larger peak value (Marker1) at -41.88dB relative to the carrier amplitude (Marker1R).

3.6 Phase Noise

Phase noise is defined as the single-sideband phase noise of the unmodulated carrier signal after HPA output. Excessive phase noise interferes with the modulated signal and affects signal quality. The phase noise testing method is similar to the output spectrum testing method, using the same test block diagram as shown in [Figure 4: see original paper]. The unmodulated single-carrier from the modulator is sent to the upconverter, and the RF modulated signal from the HPA through the coupler is sent to the spectrum analyzer to read phase noise at offsets of 10Hz-100Hz, 100Hz-1kHz, 1kHz-100kHz, and 100kHz-4MHz from the carrier. The phase noise test result interface is shown in [Figure 9: see original paper], displaying phase noise of -85.89dB/Hz.

4. Conclusion

There are many additional testing items for radio and television digital satellite uplink systems, including control and monitoring systems, network management systems, power supply systems, and antenna feed systems, all requiring regular maintenance and testing. Particularly in HPA measurement, we should strive to make the testing environment as close as possible to actual operating conditions, ensuring that input and output levels of modulators, upconverters, and HPAs operate within the normal mid-range and avoiding equipment 极限工作状态, so that test results can accurately reflect the HPA's actual operating status. To ensure healthy operation of the satellite uplink system, we must conduct routine technical indicator testing according to maintenance procedures, enabling timely detection and resolution of potential faults to guarantee safe broadcasting of radio and television programs.

References [1] GENIV2003 High-Power Klystron Power Amplifier Installation and Operation Manual.
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