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SATCOM Simulator Speeds MSS Deployment and Lowers Costs

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ABSTRACT: Mobile satellite systems (MSS) are being proposed and licensed at an accellerating rate. How can the design, manufacture and performance of these systems be optimized at costs that allow a reasonable return on investment?

The answer is the use of system simulation techniques beginning early in the system design and continuing through integration, pre and post-launch and in-orbit monitoring. This paper focuses on using commercially available, validated simulation instruments to deliver accurate, repeatable and cost effective measurements throughout the life of a typical mobile satellite system.

A satellite communications test set is discussed that provides complete parametric test capability with a significant improvement in measurement speed for manufacturing, integration, pre-launch and in-orbit testing. The test set can simulate actual up and down link traffic conditions to evaluate the effects of system impairments, propagation and multipath on bit error rate (BER), channel capacity and transponder and system load balancing. Using a standard set of commercial instruments to deliver accurate, verifiable measurements anywhere in the world speeds deployment, generates measurement confidence and lowers total system cost.

THE BASIC QUESTIONS.

A mobile satellite system (MSS) consists of satellites, gateways which link the system to other fixed services, command and control earth stations, and mobile users as shown in Figure 1. Each of these elements is extensively computer modeled and simulated during system proposal and design. However, as the implementation of the system progresses through integration, launch and deployment, simulation techniques are less commonly used. Many time consuming measurements on components, sub-systems and communications links replace these simulations, often with a loss of accuracy. The basic questions to be answered remain: what level of operability exists within the system, how has performance changed over time and what is the optimal allocation of system capacity that will maximize the number of users and revenues?

To answer these questions satellite systems undergo extensive parametric testing at integration, prior to launch, after insertion into orbit and throughout operational life. The number of tests, their duration and the need to repeat them at several stages makes deployment a time consuming and costly process. Table 1 illustrates the redundancy of testing in present systems. Two alternatives are to reduce the time per test and to replace some of the testing with simulations. The satcomm test set discussed here achieves both of these improvements in a single set of test instrumentation.

Table 1. Typical Satellite System Test Matrix

	Integration	Pre-launch	IOT	E/S
Effective Isotropic Radiated Power (EIRP)				
Beacon EIRP	X	X	X	X
Carrier EIRP	X	X	X	X
Modulated EIRP	X	X	X	X
EIRP Stability	X	X	X	X
Saturation Flux Density	X	X	X	
Freq Response				
Gain & Gain Flatness				
Small Signal	X	X	X	X
Saturated	X	X	X	X
Group Delay	X		X	
NPR	X		X	
Channelization	X	X	X	X
G/T	X	X	X	X
Antenna Patterns	X		X	X
Cross Polarization Isolation	X		X	X
Sidelobe Patterns	X		X	X
Telemetry Command Sens & AGC	X	X	X	
Transponder Transfer Characteristics	X	X	X	
Beacon Mod Index	X	X	X	X
Frequency Stability	X	X	X	X
E/S Receiver Sens & Characteristics				X

THE "SMART STIMULUS" CONCEPT

Traditional parametric test techniques employ relatively simple signal generators as test stimuli. These generators allow control of frequency, carrier amplitude and basic modulations. The response of the device under test is analyzed by instruments that measure power or frequency, analyze or demodulate signals to determine modulation parameters, and count data errors to evaluate transmission quality. As communications signals have increased in complexity, the measurement instrumentation also has become more complex. Simple measurements may not completely characterize the effect the parameter under test has on system performance and comprehensive measurements are often tedious and slow.

When a satellite is placed in orbit the test environment becomes more complex. Measurement complexity is compounded by the time delay proportional to the range of the satellite from the earth station, variations in delay due to positional drift or orbit, doppler effects due to the satellite's velocity, transponder frequency translation and any reformatting of data packets in the satellite.

Many of these problems can be overcome and the measurement instrumentation simplified by using what has been termed a "smart stimulus" as a test signal source. Such a stimulus can be tailored to overcome many practical difficulties that arise in the course of making a measurement. These include the effects of frequency translation and time delays in the DUT, removal of test path amplitude and phase errors, etc. Errors caused by a time varying measurement environment can also be minimized.

The Hewlett-Packard HP 8791A Frequency Agile Signal Simulator (HP-FASS) combines direct digital synthesis technology with digital signal processing and fast transform techniques. HP-FASS is an ideal "smart stimulus" for satellite communications testing. Utilizing high clock rates, proprietary digital to analog conversion technology and a unique Waveform Generation Language, this software reconfigurable generator can modify its output signals in real time with digital precision, accuracy and repeatability. For example, HP-FASS can change its output signal to offset the effects of doppler caused by a rapidly moving low earth orbit (LEO) satellite. HP-FASS can reduce test times in repetitive measurements like gain and group delay by recalling stored sequences of frequency, amplitude and modulation and generating corrections on the fly as needed. Compared to traditional signal sources HP-FASS reduces measurement times, generates higher precision signals and measurement results, and allows the use of a simpler, lower cost test system with fewer interconnects and less complex signal routing.

Figure 2 is a block diagram of a satellite communications test set based upon the HP-FASS. This test set performs the parametric tests listed below the figure. A switching matrix is not shown since its complexity depends on the number of interconnects to the DUT. However, the use of a single HP-FASS as the stimulus and a minimum amount of measurement instrumentation greatly simplifies the signal routing.

PARAMETRIC TESTING

As discussed above many parametric tests are performed on satellites and earth stations to quantify their performance. The HP-FASS based test set significantly reduces test times for many of these tests. In addition, test accuracy and repeatability are equal or better than traditional techniques. For example, a multi-tone amplifier intermodulation test was used to establish a benchmark for comparing measurement speed. A 10 tone measurement was performed at 10 power levels on all 22 channels of each transponder.

Traditional techniques use multiple signal generators as a test stimulus. Since the intermodulation distortion is directly proportional to the peak amplitude of the input signal, the phase relationship between the various input tones is critical. Conventional signal generators do not allow control of the phase of the individual tones. This slows the measurement because the worst case phase relationship occurs only rarely as the signal sources drift in phase. The FASS-based test set performs multi-tone measurements significantly faster than traditional techniques. In the benchmark example the HP-FASS based test set completed the measurement in one-third the time of a conventional test system. HP-FASS provides complete control of both the amplitude and the phase of each individual tone. Tones may be continuous wave (CW) carriers or may have modulation imposed upon them for signal simulation.

Another type of intermodulation test is the Noise Power Ratio (NPR) test. Traditionally this test uses wideband noise sources, amplifiers, filters and attenuators to generate a white noise spectra that has a narrowband notch at the frequency of interest. While conceptually simple, in practice this test system has difficulty producing accurate results repeatably. Many hours of calibration and tuning are involved in NPR measurements on the high power amplifiers in a typical transponder. The HP-FASS test set generates a pseudo-noise spectra with a precisely controlled notch. Dynamic ranges greater than 60 dB are achieved. The HP-FASS makes this measurement fast, easy, accurate and very repeatable. Figure 3 shows the output spectra from an HP-FASS generating a NPR test signal.

Group delay is a parametric test that is performed to quantify transponder performance and as a health check during routine monitoring. Traditionally a vector network analyzer is used for benchtop component and sub-system tests that do not involve frequency translation, while a communications link analyzer is used for transponder tests and in-orbit testing. Other techniques which require reference signals from the test stimulus eliminate their use forin-orbit measurements.

A single test set built around a HP-FASS can be used for all the group delay measurements from component level through spacecraft integration to in-orbit testing. The basic technique is similiar to that used with the communications link analyzer but is much faster. Since the HP-FASS has the advantage of digital precision in its output signals as well as 250 nano-second frequency agility, a fast frequency chirp is used to sweep a carrier across the device under test. AM or FM modulation is applied to the carrier and the modulation is recovered at the output of the DUT. AM is used for devices not in amplitude saturation while FM is used for saturated devices. The measurement technique is modified only slightly for in-orbit tests. Here where changes in range contribute errors (adding tilt to the group delay plot) and doppler shift complicates the measurement, periodicly returning to a reference frequency provides the information necessary to eliminate these errors. The digital precision and agility of the smart stimulus makes this measurement fast, easy to perform and very accurate.

Table 2 lists expected measurement times and accuracies for the HP-FASS test set when performing several typical satellite system parametric tests.

Table 2. HP-FASS Test Set Performance

Measurement	Time	Uncertainty
Gain (1 point)	2 sec	+/- 0.3 dB
Gain (500 points)	9 sec	+/- 0.3 dB
Group Delay	20 sec	+/- 1.5 nsec
AM/PM Conversion	20 sec	+/- 1 degree
Phase vs Amplitude (20 dB range)	20 sec	+/- 1 degree
Phase Noise (5Hz-100kHz)	180 sec	+/- 1.5 dB
Intermod Dist (NPR)	60 sec setup 180 sec/ten levels	+/- 0.3 dB
Spurious Search	30 sec/ 1 transp BW	+/- 2 dB
G/T	30 sec	TBD
EIRP (10 tones)	30 sec	+/- 0.5 dB
Multichannel Characterization	200 sec	+/- 0.2 dB flatness +/- 0.2 dB gain

SIGNAL and ENVIRONMENT SIMULATION

Payload designers, system planners and earth station developers need to know how the satellite system will perform with realistic traffic loading prior to launching the system into space. Once the MSS is placed in service, system operators and planners must monitor performance to optimize efficiency and minimize degradations to users. A satellite simulator based upon the HP-FASS provides fast, repeatable and cost effective evaluation and validation of systems under realistic conditions. Simulated up and down link signals can be used to evaluate payload designs, validate earth station design and optimize system monitoring.

Payload Design and Evaluation

Signal simulation is a powerful method to improve the performance and speed the development of payloads. First the design is simulated with one of the many communications simulation software packages available. Next the hardware is evaluated using test signals identical to those used in the computer simulations.

Bit error rate testing (BERT) of payloads, intermodulation testing of amplifiers and transponders, evaluation of tracking, telemetry and control (TT&C) links and payload integration and performance verification is greatly enhanced using realistic modulated signals.

Earth Station Design and Validation

Verifying that the design of earth stations meets system specifications can be a difficult and lengthy task. The HP-FASS was used to validate the design of an earth station monitoring system. Figure 4 illustrates one of the signals used in this design validation. Each channel in this multi-channel signal can have its data, data rate, modulation type, channel filter mask and amplitude individually described to replicate actual traffic loading. Having the same test signal available at all earth stations ensures consistent and precise earth station evaluation and trouble shooting.

System Monitoring

Simulated up and down link signals also can be used to determine channel capacity, to load balance transponders and to plan and evaluate system performance once a system is placed in service. Accurate evaluation of bit error rate and signal to noise ratio for different transponders and antenna beam coverages requires realistic signals. A source of precisely repeatable signals maximizes the accuracy of periodic comparisons of link performance. Accurate evaluation of link margins is critical to optimizing the utility and profitability of the system.

SYSTEM IMPAIRMENTS and PROPAGATION EFFECTS

The HP-FASS not only provides precision "ideal" signals, it can also distort them to model the effects of system impairments and propagation. Simulating these effects allows evaluation of system operating margins in a controlled environment. Transponder and earth station imperfections including transmitter and receiver gain and quadrature errors, amplitude compression, noise and end of life performance degradation can be effectively simulated. Figure 5 demonstrates two HP-FASS generated 32 QAM signals. The first has zero I/Q quadrature error, while the second has precisely 5 degrees of quadrature error.

HP-FASS can simulate doppler effects more precisely than simple signal generators. A moving platform imparts a frequency shift to the modulation components in addition to that imparted to the carrier. Simple generators usually are limited to simulating doppler shift on the carrier only.

Propagation effects can be simulated including rain attenuation and fading. Multipath simulations can be performed aross the entire 40 MHz modulation bandwidth of the HP-FASS. This allows complete multipath evaluation of an entire transponder with one simulation.

CONCLUSION

A satellite communications test set has been described that provides parametric test capability and realistic up/down link traffic simulations. Impairments and propagation effects can also be added for complete system evaluation and margin analysis. The test set uses commercially available instrumentation at the heart of which is the HP 8971A FASS "smart stimulus". The test set is easy to use and delivers faster, more repeatable and higher precision test results compared to conventional systems. The same test set can be used in all test situations from component manufacture through satellite integration to in-orbit test. The ease of generating realistic signal and environment simulations should lead to wider use of these techniques in place of some parametric tests. The use of simulations should improve the characterization of the total satellite system and lead to faster, more economical system deployment.

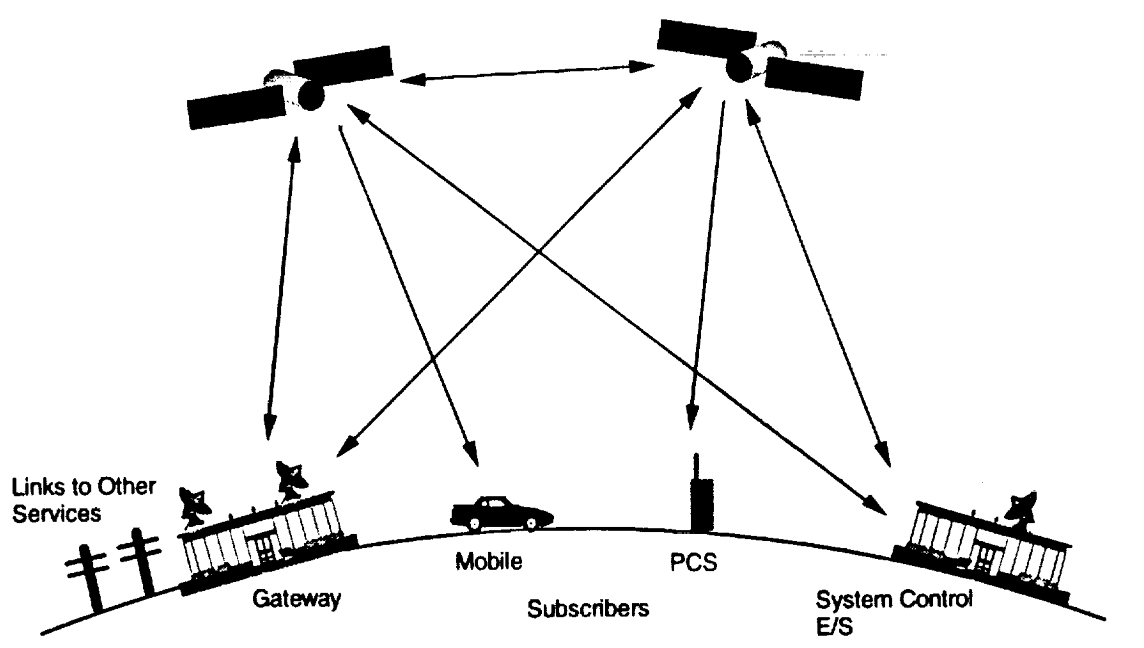

Figure 1. Elements of a typical Mobile Satellite System

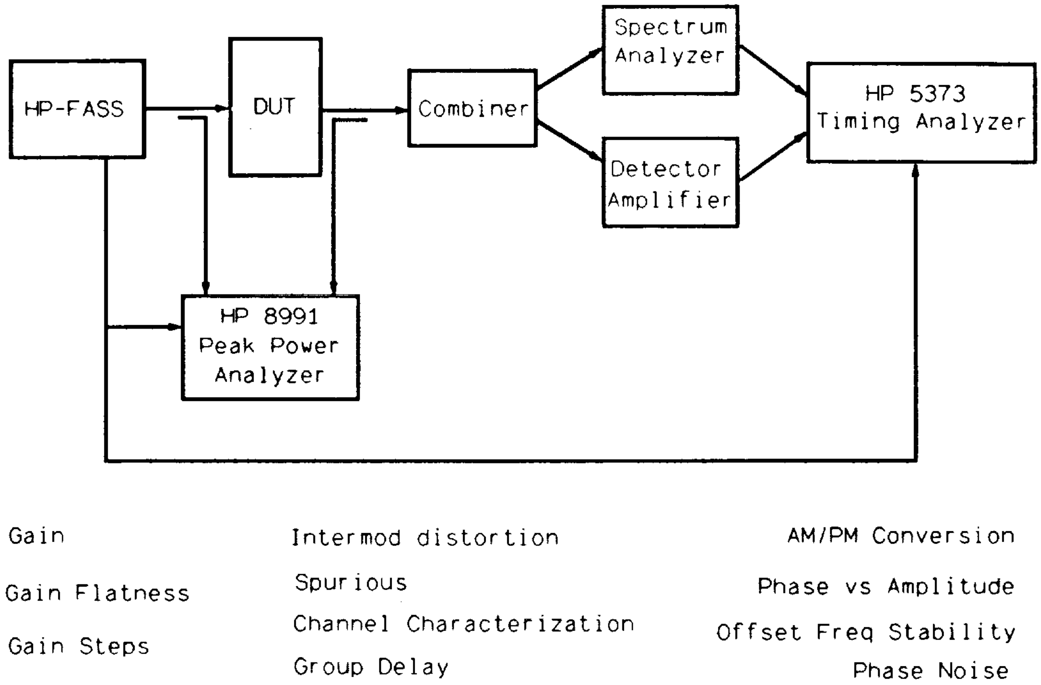

Figure 2. Block diagram of satellite communications test set based upon HP-FASS as a "smart stimulus".

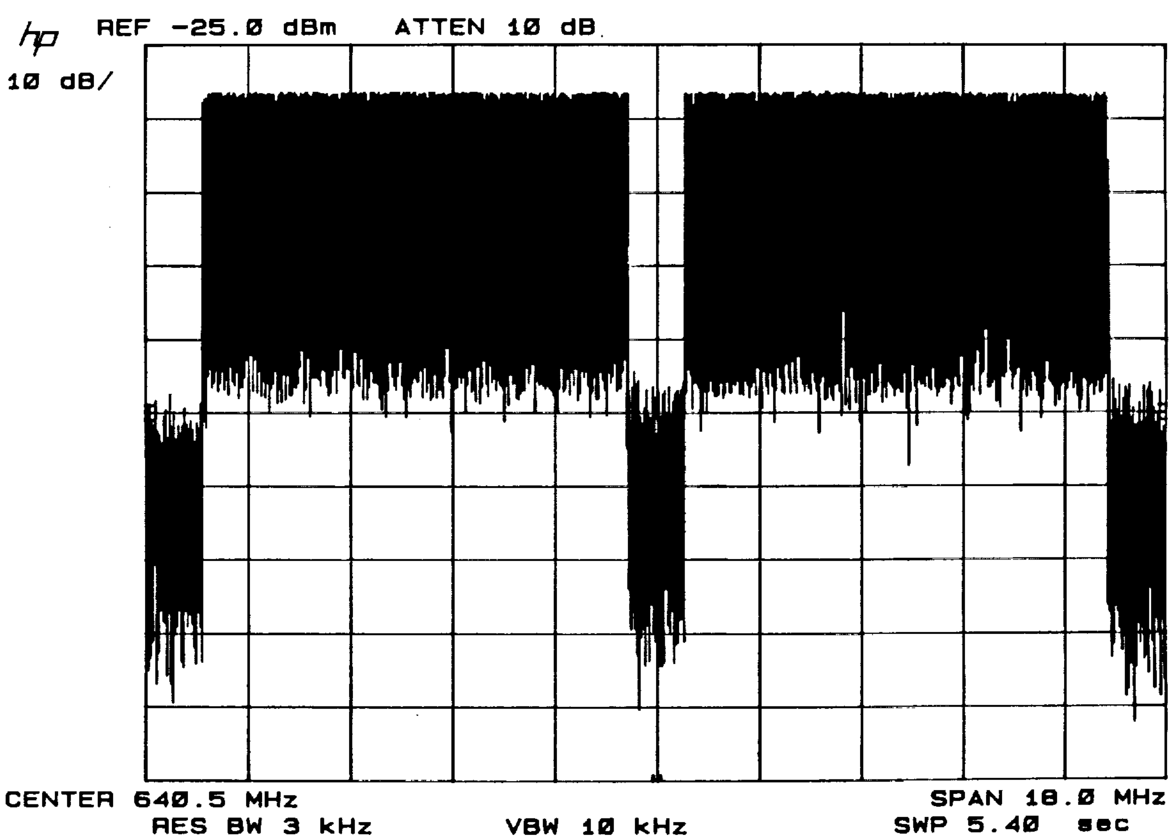

Figure 3. Noise Power Ratio measurement spectra from HP-FASS.

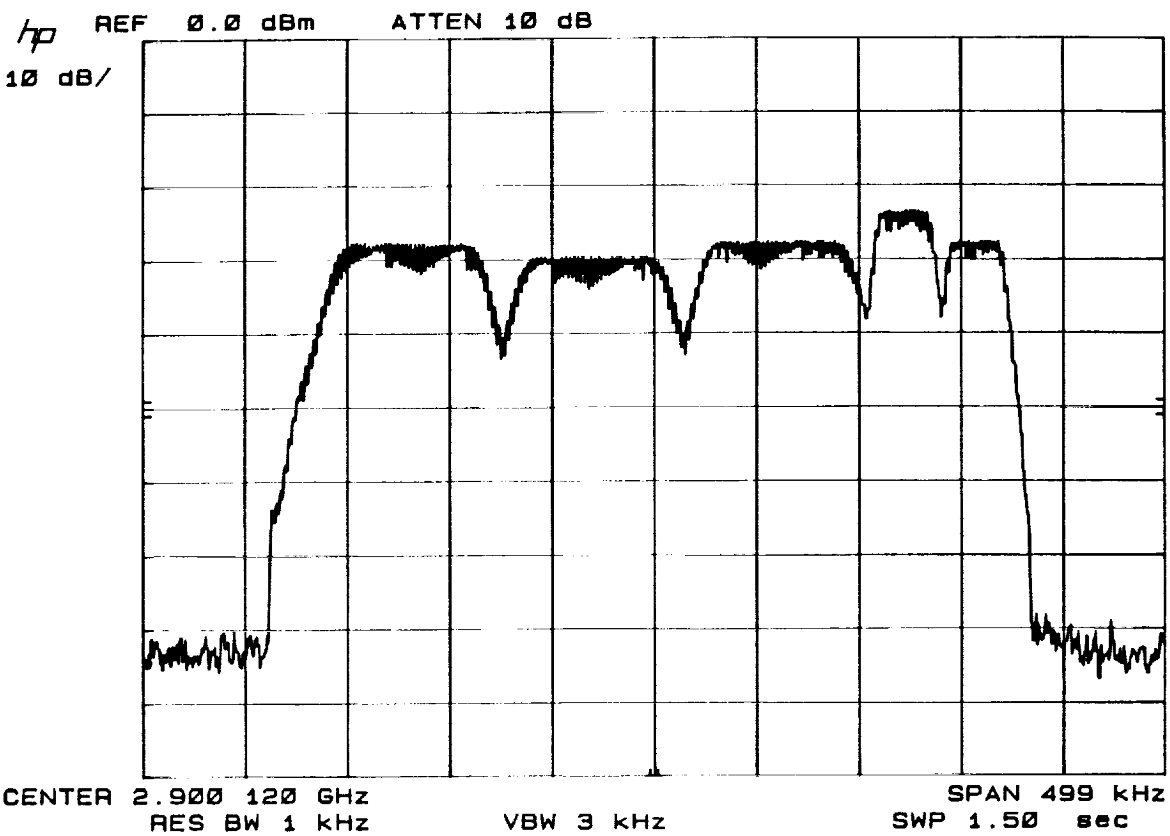

Figure 4. Multi-channel signal from HP-FASS simulating five channels with various amplitudes and data rates filtered per Intelsat masks. All channels are QPSK modulated.

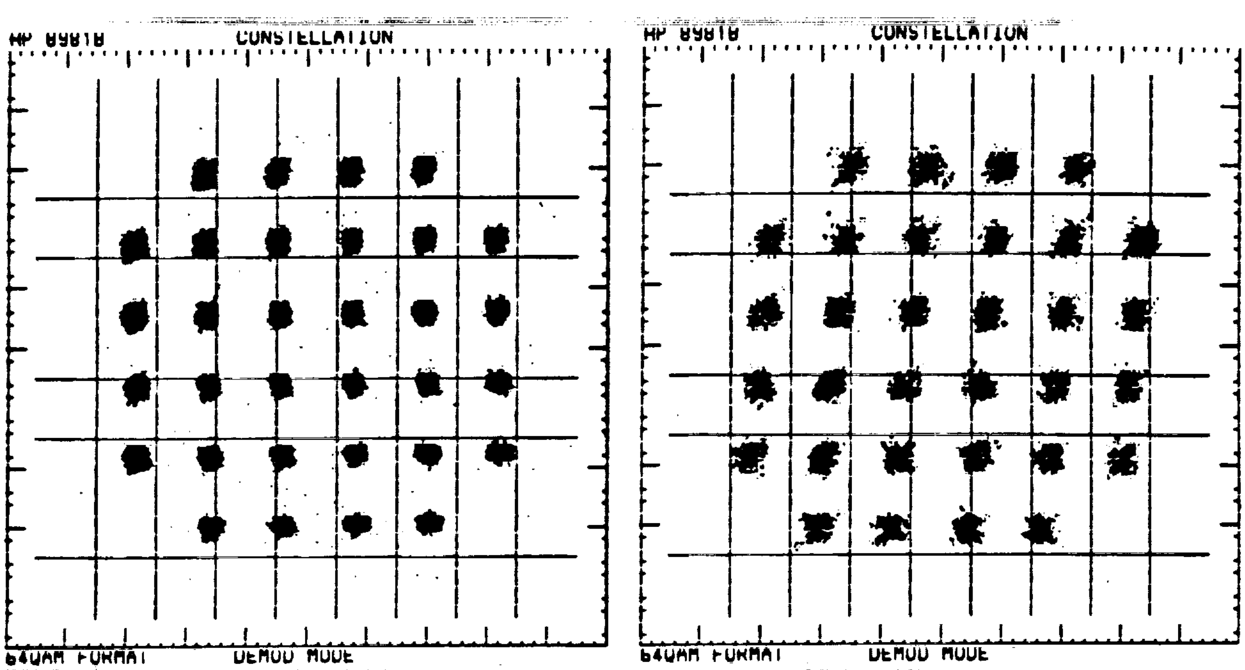

Figure 5. 32 QAM constellations generated by HP-FASS. Zero I/Q quadrature error on the left and 5 degrees quadrature error on the right.