Block III X-Band Receiver-Exciter

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The development of an X-band exciter, for use in the X-Band Uplink Subsystem, has been completed. The exciter generates the drive signal for the X-band transmitter and also generates coherent test signals for the S- and X-band Block III translator and a doppler reference signal for the doppler extractor system. In addition to the above, the exciter generates other reference signals that are described in this article. Also presented is an overview of the exciter design and some test data taken on the prototype. A brief discussion of the Block III doppler extractor is presented.

I. Introduction

A new X-band exciter has been developed for the X-Band Uplink Subsystem for use in the Deep Space Network (DSN) that will provide the required $\Delta f/f$ stability of 5.2×10^{-15} for 1000 second integration periods. A similar (prototype) exciter was developed earlier [1] and evaluated at DSS 13. The evaluation has been completed and test results verified that its mechanization was appropriate for the new DSN exciter.

The exciter design is discussed in Sections II through VII, covering the overall block diagram generation of the X- and S-band receiver test signals, generation of the receiver 1st L.O., and generation of the reference signals to the ranging and doppler subsystems. In addition, the exciter phase control loop design is described, as well as the command phase modulation (and verification) and ranging modulation capabilities.

II. Basic Exciter Signal Generation

A simplified block diagram of the exciter is shown in Fig. 1. The configuration is similar to that described in [1] with the exceptions of the mechanization of the doppler reference signal, the references to the ranging and doppler subsystems, and the newly included receiver 1st L.O. signal. To generate the X-band exciter signal, F_x, a 43.125 MHz synthesizer input signal is multiplied by a factor of 16 to 690 MHz and mixed with 6500 MHz to provide the 7200 MHz sum frequency. The 6500 MHz is generated by multipling a 100 MHz input reference (from the station hydrogen maser) by a factor of 65. The 7200 MHz is selected at the mixer's output by a bandpass filter and then used as the basic exciter signal. The exciter signal is then amplified and connected through X-band command and ranging phase modulators. An RF relay is used for enabling or disabling the exciter output.

Prior to multipling the 43.125 MHz synthesizer signal, the signal is passed through a 43 MHz voltage controlled phase shifter module used in the exciter phase control loop (described below).

III. Reference Exciter

A second X-band signal is generated within the exciter in a manner similar to the exciter signal. The 43.125 MHz input is divided into two paths. One path is used for driving the exciter channel (as described above). The second path is multiplied by another X16 multiplier and mixed with the 6500 MHz reference signal to yield an unmodulated X-band reference signal. This signal is used as the phase detector reference within the phase control loop.

IV. Exciter Functions

A. Exciter Phase-Control Loop

To reduce phase variations in the transmitted signal (that can be caused by component variations due to temperature changes, klystron characteristics, etc.), a phase correcting loop is incorporated within the exciter. A phase correcting loop is used in the original DSS 13 exciter, but the mechanization of the DSN exciter loop has been redesigned to improve loop gain and linearity. The original design did not use a reference exciter and the loop error was applied directly to an X-band phase shifter in the exciter path. To attain the required loop gain, high dc amplification was required, which resulted in excessive loop nonlinearities (amplifier saturation) with large phase error conditions.

Figure 2 is a simplified diagram of the DSN exciter phase control loop flow (heavy lines). When the phase control loop is used for controlling the output of the transmitter relay, K_x is actuated to allow the transmitter signal to be applied to the signal port of the loop detector and phase compared with the exciter reference signal. When relay K_x is in the exciter position, the loop controls only the phase of the exciter output. The error at the detector's output (due to the nonquadrature relationship of the two signals) is applied to a low pass RC filter and then amplified by a dc amplifier.

The filtered voltage, static phase error (SPE), from the amplifier is then applied to the dc control port of the 43 MHz voltage controlled phase shifter module. The phase of the 43 MHz exciter signal, applied to the input, is shifted proportionally to the SPE voltage and then multiplied by 16 by multiplier M1. The 690 MHz from the X16 is then mixed with the 6500 MHz reference signal to provide the phase shifted X-band exciter output signal. The correction forces the phase of the transmitter signal toward quadrature, relative to the reference signal, at the phase detector inputs. The gain of the voltage controlled phase shifter followed by the X16 multiplication increases the loop gain, permitting an appreciable reduction in dc amplifier gain that results in improved loop linearity in the presence of large phase errors.

The design -3 dB bandwidth of the loop is 2 Hz to ensure that low frequency command signals are not reduced by the loop response. The design loop gain is 100 to reduce transmitted phase perturbations by that factor.

A mathematical model of the loop is shown in Fig. 3 and the complex loop transfer function, $H(s)$, is derived below the figure. When the term 16 $k_d\ G_a\ K_\phi$, in the denominator, is set equal to the total loop gain, G_T, the loop transfer function becomes:

$$H(s) = \frac{RCs + 1}{RCs + G_T + 1}$$

Letting $s = jw$ and taking the absolute value of the transfer function:

$$|H(jw)| = \frac{\sqrt{((RCw)^2 + 1)}}{\sqrt{((RCw)^2 + (G_T + 1)^2)}}$$

To solve for the loop RC time constant, the cutoff frequency w_c, is set to $2\pi f_c$, where f_c = 2 Hz and G_T = 100. Setting $|H(jw)| = 2^{-1/2}$ and solving for RC:

$$RC = \frac{\sqrt{(100^2 + 200 - 1)}}{(2)(\pi)(2)} = 8.037 \text{ sec}$$

The loop filter time constant used within the exciter is 8 seconds.

Substituting 8 for RC, $2\pi f$ for w, and 101 for $G_T + 1$, the transfer function becomes:

$$|H(j2\pi f)| = \frac{\sqrt{((8 \times 2\pi f)^2 + 1)}}{\sqrt{((8 \times 2\pi f)^2 + (101)^2)}}$$

or

$$|H(j2\pi f)| = \frac{\sqrt{(2526.62 f^2 + 1)}}{\sqrt{(2526.62 f^2 + 10{,}201)}}$$

which is the ideal design loop response. This is plotted in Fig. 4.

B. Command Modulator and Verification

The X-band exciter signal is divided into two paths prior to application to the command phase modulator. One path allows the exciter to be phase modulated by command signals and the second serves as a phase detector reference, where it is phase compared to the modulated signal. The modulated signal is again divided into two paths—one path for the exciter output and the second for command verification.

The verification path is coupled through an X-band voltage controlled phase shifter, used within, in a phase correcting loop, and then coupled into the signal port of the verification phase detector. The resultant detector output, when the reference and modulated signals are in quadrature, is a demodulated replica of the command input signal with the exception that, since the output of the detector is sinusoidal with phase, the amplitude is compressed relative to the original modulation signal. The verification signal amplitude, A_m, is optimized at a modulation index of 45 degrees, and the amplitude can be closely computed by $A_m = 0.37 \sin(\text{mod index})$, where the modulation index is in degrees. The detector output is coupled into a module containing a video amplifier that provides two verification outputs that are coupled through coaxial cables to the command subsystem.

The module also contains an active low pass filter circuit whose output is coupled into the voltage control port of the phase shifter. The filter circuit controls the phase of the modulated signal, keeping it near quadrature relative to the reference signal. The design gain of the loop is 100 to reduce phase drifts to a negligible amount. The design frequency response is 2 Hz to prevent the tracking out of command signals in the 50 Hz range.

The verification phase control loop is mechanized somewhat like the exciter phase control loop, with the exception that it does not have the advantage of the phase gain of the 43 MHz voltage controlled phase shifter and its following $\times 16$ frequency multiplier. It was therefore necessary to increase the gain of the dc amplifier to obtain a loop gain of 100. Since the loop gain and cutoff frequency of the verification loop is the same as the exciter loop, the loop filter RC time constant is 8 seconds.

The high frequency response is designed to have a -1 dB cutoff of 150 kHz and is set by a low pass filter within the modulation control module.

C. Range Phase Modulator

A second X-band modulator follows the command modulator for application of ranging signals to the uplink signal. The modulator, including the range modulation control, is similar to the command modulator with exception of the modulation bandwidth. The ranging bandwidth is in excess of 5 MHz at the -3 dB point. By means of the exciter controller, up to two modulation signals can be applied to the X-band carrier.

D. Exciter On/Off Control

The DSS 13 X-band exciter was not equipped with an exciter on/off control to disable the drive to the transmitter input. The DSN exciters are equipped with a control to disable the output signal by means of the exciter controller. In addition, the control relay controls the transmitter warning light, located in the antenna.

E. Coherent X- and S-Band Test Signals

Coherent X- and S-band test signals are generated within the exciter. The method used for generating these signals is described in [1], but by reference to Fig. 1, it can be seen that the $F_x/80$ signal is multiplied by a factor of 10,480/749 (by means of a $\times$ 2096/749 and a $\times$ 5 multiplier) and mixed with a sample of the exciter signal to provide a sum frequency of 880/749 F_x, which is the coherent X-X receiver frequency. Similarly, the coherent S-band signal is generated by multiplying the $F_x/80$ signal by a factor of 40,720/749 (by means of a $\times$ 8144/749 and a $\times$ 5 multiplier), to generate a coherent 509/749 F_x signal that is mixed with a sample of the exciter output to provide a 240/749 F_x difference signal, the coherent X-S receiver frequency.

F. Receiver First L.O. Generation

To generate the coherent 640/749 1st L.O., the $F_x/80$ signal is multiplied by a factor of 8720/749 (by means of a 1744/749 multiplier followed by a $\times$ 5 multiplier), to produce a coherent 109/749 F_x signal. This signal is mixed with a sample of the unmodulated exciter signal to produce the coherent L.O. used to drive the X- to S-band down converter mixer. The L.O. signal down converts the received X-band to the required S-band input to the Block III receiver (880/749 F_x - 640/749 F_x = 240/749 F_x). The mixer output is filtered, amplified, and applied to an output terminal on the exciter.

G. 48 MHz Doppler Reference

The 48 MHz doppler reference signal is generated by multiplying the $F_x/80$ signal by a factor of 400/749 to obtain the required 5 $F_x/749$ ratio. The doppler signal is then coupled to the Block III receiver into the doppler reference distribution module (described below).

H. Tracking Subsystem References

To generate the 66 MHz exciter reference signal, F_{range}, for the ranging subsystem, the $F_x/80$ signal is multiplied by a factor of 11/15. The ratio of the output of the module to the exciter frequency is $F_{\text{range}} = 11\ F_x/1200$. This mechanization was used to keep the frequency near the frequency supplied to the ranging subsystem from the Block III S-band exciter. The 22 MHz exciter reference to the MDA, F_{MDA}, is generated within the same module by dividing the 66 MHz by a factor of 3. The ratio of this signal to the exciter output is F_{MDA}/F_x = 11/3600.

V. Physical Configuration

The exciter is housed in three wall mounted Hoffman enclosures, each 36 in. by 24 in. by 8 in. Two of the enclosures contain the rf hardware and the third contains the power supplies and controller board. One rf enclosure (Test Signal and Reference Generator Assembly) contains the ×16 multipliers, the 43 MHz phase shifter, the 13/16 frequency shifter and mixer, and all the frequency shifters used for generating the test and reference signals. The second rf enclosure (Mixer/Modulator Assembly) contains the mixers, the command and range phase modulators (and their associated controllers), the components for the exciter and confirmation phase control loops, the exciter output amplifier, and the exciter relay. The third box contains the power supplies and the single circuit board exciter controller. The controller is briefly described below.

VI. Temperature Stabilization

The components within each of the rf enclosures are ovenized to ensure signal stability over ambient variations of plus and minus 5°C around the mean elevation room temperature of 22°C. The temperature stability of the rf enclosures was measured in the JPL Environmental Lab. The measurements showed that the internal temperature of the Test Signal and Reference Generator Assembly will change 1°C for an ambient change of 7°C and the temperature of the Mixer/Modulator Assembly will change 1°C for a 10°C change.

VII. Controller

The exciter functions are controlled and monitored by means of a manual control panel located in the control room. A single controller circuit board is located within the power supply box in the antenna equipment and a two circuit board system is located within the control room equipment. One of the control room boards is used for communicating with the antenna (sending configuration data and storing monitor data) and the second is reserved for future interfacing with the Block III Monitor and Control Subsystem. A Universal Asynchronous Receiver/Transmitter (UAR/T) integrated circuit (IC) is used for transmitting control data to the antenna unit and a similar IC is used in the antenna unit to send monitor data to the control room. A CLEAR pulse is transmitted from the control room to the antenna at approximately 10 pps. The pulse synchronizes the circuitry at both ends and permits new data transmission at 10 times per second.

Control data actuates relays within the exciter to their required position, such as exciter on or exciter off, and monitor data indicates relay position. Also, the rf output power of most of the modules is monitored in the form of a single bit to indicate the presence or absence of rf. Other monitor data are power supply outputs, internal oven temperatures, and exciter output.

VIII. Doppler Reference Distribution

The 5 $F_x/749$ doppler reference signal (about 48 MHz), generated by the exciter, is coupled through coaxial cable to the control room and into the input of the doppler reference distribution module. Figure 5 is a simplified block diagram of the module showing the internal mixing processes that generate the 22 MHz reference signals for the doppler subsystem. The 22 MHz is not the same as that supplied from the ×11/45 multiplier in the exciter. To generate the 22 MHz, a 26 MHz signal is generated from 1, 10, and 45 MHz reference inputs and mixed with the 48 MHz doppler reference from the exciter. As shown in Fig. 5, there are two mixers that generate the 22 MHz for the doppler subsystem—one from connector J6 that is permanently generated by mixing the 48 MHz with the 26 MHz reference, and one from J7, generated by mixing the 26 MHz with the 48 MHz from the exciter or the 48 MHz from the simulation synthesizer (sim synth), depending on the selected relay position within the module.

A third output, J4, supplies the 48 MHz to the Block III doppler mixer and ×48 multiplier and can be selected from the exciter or the sim synth.

IX. Doppler Extraction

Figure 6 is a functional diagram of the complete doppler extraction system. Within the doppler mixer and ×48 frequency multiplier module, the 48 MHz doppler reference from the exciter or the sim synth is mixed with twice the receiver VCO frequency, and the resulting difference is multiplied by a factor of 48 to yield 50 MHz doppler. The signal is then divided into two paths—one path is mixed with an externally applied 45 MHz reference to give a 5 MHz doppler difference that is connected to an output connector. The second path is mixed with a selectable 49 or 51 MHz reference to give a plus or minus (1 MHz doppler) difference that is also connected to output connectors on the module.

X. Exciter Test Results

A. Exciter Phase Correcting Loop

Frequency response measurements were made on the DSN exciter to verify the exciter phase correcting loop response. The measured response is shown in Fig. 4, along with the ideal design response. Using the measured -3 dB point and the measured loop constants, the gain was computed to be 112. This was verified by a second measurement made by shorting the loop and introducing a known phase error (by calibrating the loop phase detector output), and then enabling the loop and again measuring the phase detector output.

B. Command Verification Phase Correcting Loop

The measured response of the command verification phase correcting loop is shown in Fig. 7. During the measurements, the exciter phase correcting loop was operating and therefore the response at 2 Hz is about -6 dB, as expected.

C. Command Confirmation Signal Linearity

The measured command verification signal level vs modulation angle is shown in Fig. 8. The output amplitude can be closely computed by A_m = 0.37 sin (mod angle), where the modulation angle is expressed in degrees. The computed, measured, and ideal curves are also shown for comparison.

D. Control and Monitor

All control and monitor functions were verified using the prototype X-Band Controller Assembly. To date, the exciter controller has not been interfaced with a system controller.

XI. Conclusions

Measurements made on the prototype DSN X-band exciter have been performed and the results show that the rf, control and monitor, and internal phase correcting loops perform to their design criteria. To date, the exciter stability ($\Delta f/f$) measurements have not been performed, but these measurements, as well as single sideband noise spectral density measurements, will be made in the near future.

Reference

[1] R. Hartop, C. Johns, and R. Kolbly, "X-Band Uplink Ground Systems Development" *DSN Progress Report 42-56*, vol. Jan.-Feb. 1980, pp. 48-58, Jet Propulsion Laboratory, Pasadena, CA, April 15, 1980.

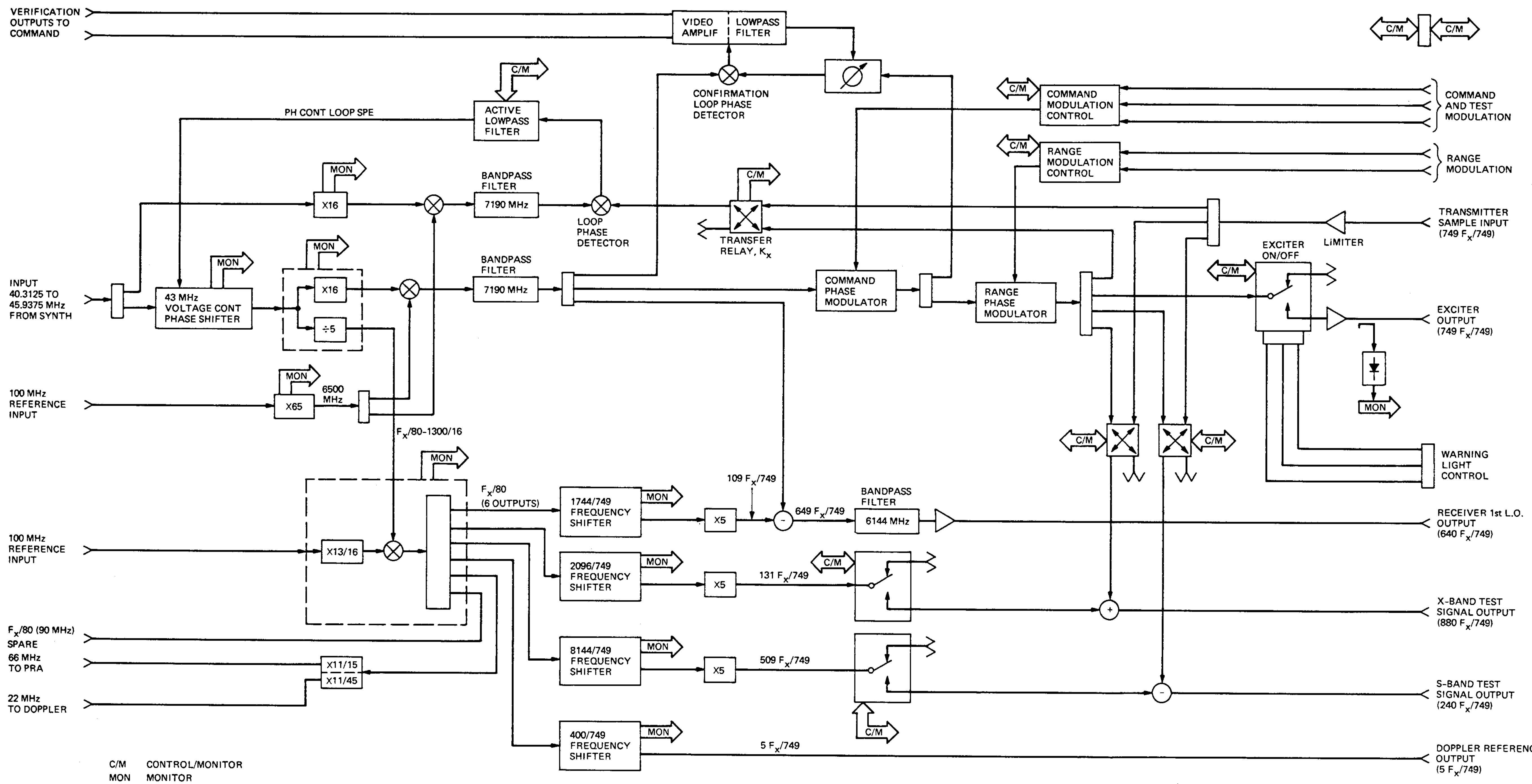


Fig. 1. X-band exciter functional block diagram

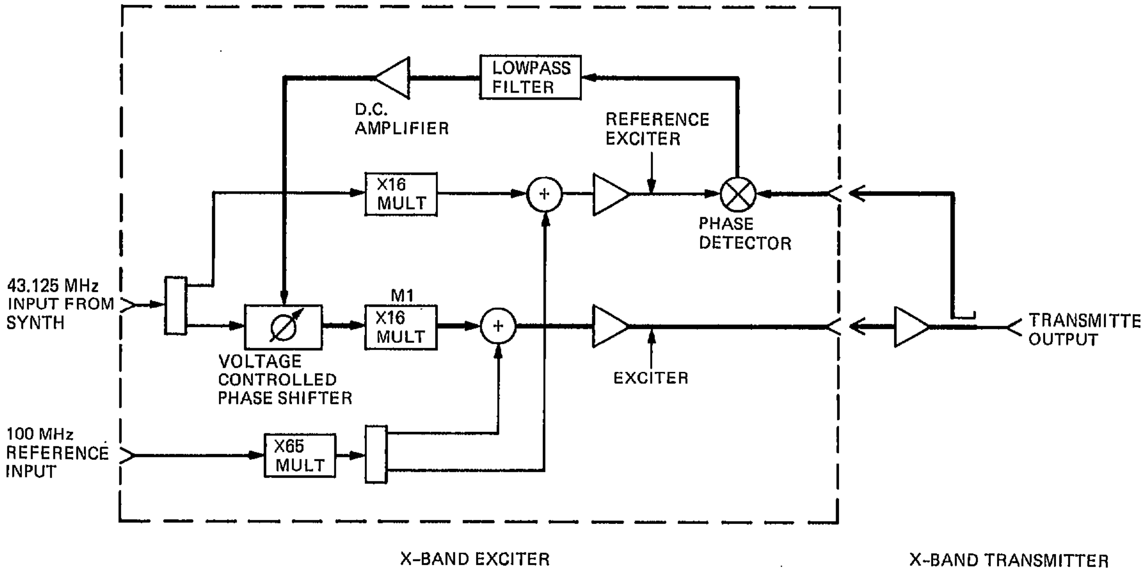
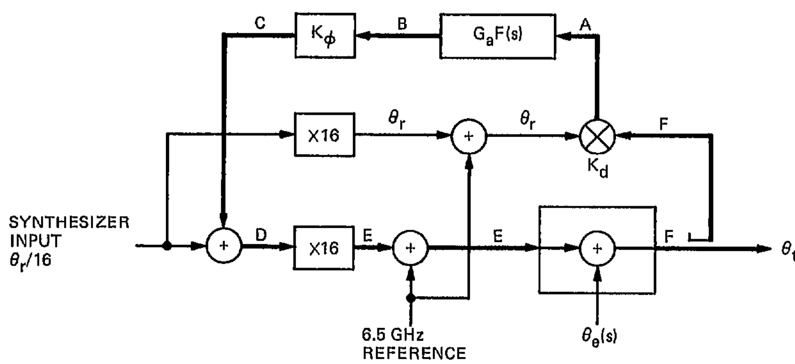


Fig. 2. X-band exciter phase control loop



POINT	FUNCTION
A	$(\theta_r - \theta_t) K_d$
B	$(\theta_r - \theta_t) K_d G_a F(s)$
C	$(\theta_r - \theta_t) K_d G_a K_\phi F(s)$, $F(s) = 1/(RCs + 1)$
D	$\theta_r/16 + (\theta_r - \theta_t) K_d G_a K_\phi F(s)$
E	$\theta_r + 16 (\theta_r - \theta_t) K_d G_a K_\phi F(s)$
F	$\theta_r + 16 (\theta_r - \theta_t) K_d G_a K_\phi F(s) + \theta_e = \theta_t$

POINT F GIVES: $\theta_t = \theta_r + \theta_e(s)\,(RCs + 1)/(RCs + 16\,G_a K_d K_\phi + 1)$

THE EXTREME RIGHT TERM YIELDS THE LOOP TRANSFER FUNCTION:

$\theta_t/\theta_e(s) = H(s) = (RCs + 16\,K_d G_a K_\phi + 1)$

DEFINITIONS

θ_r	REFERENCE EXCITER PHASE
θ_t	TRANSMITTER OUTPUT PHASE
$\theta_e(s)$	TRANSMITTER PHASE PERTURBATIONS
K_d	PHASE DETECTOR GAIN, 0.0057 V/deg
G_a	DC AMPLIFIER GAIN, 3.85 V/V
K_ϕ	43 MHz VOLT. CONTROLLED PHASE SHIFTER GAIN, 285 deg/V
F(s)	LOOP TRACKING FILTER, I/(RCs + 1), RC = 8 secs
s	LAPLACE COMPLEX FREQUENCY VARIABLE

Fig. 3. Exciter phase correcting loop, mathematical model

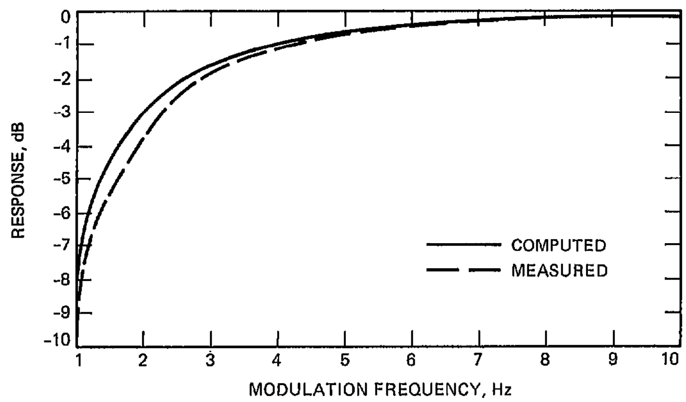


Fig. 4. Exciter phase control loop response

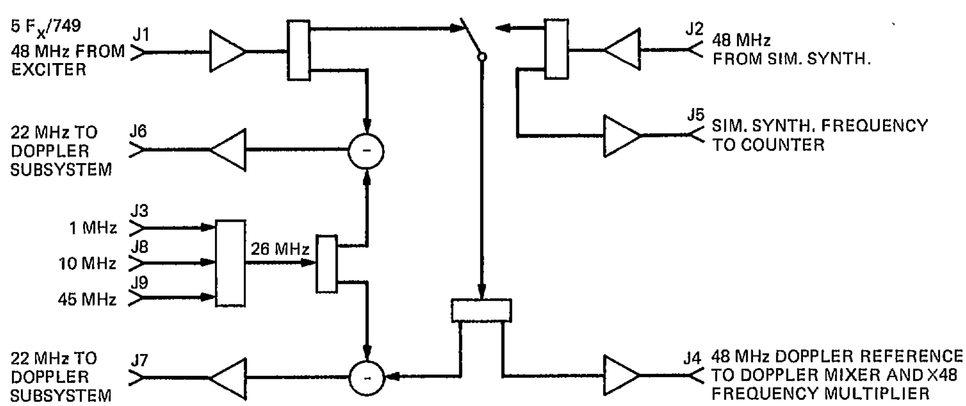


Fig. 5. Doppler reference distribution

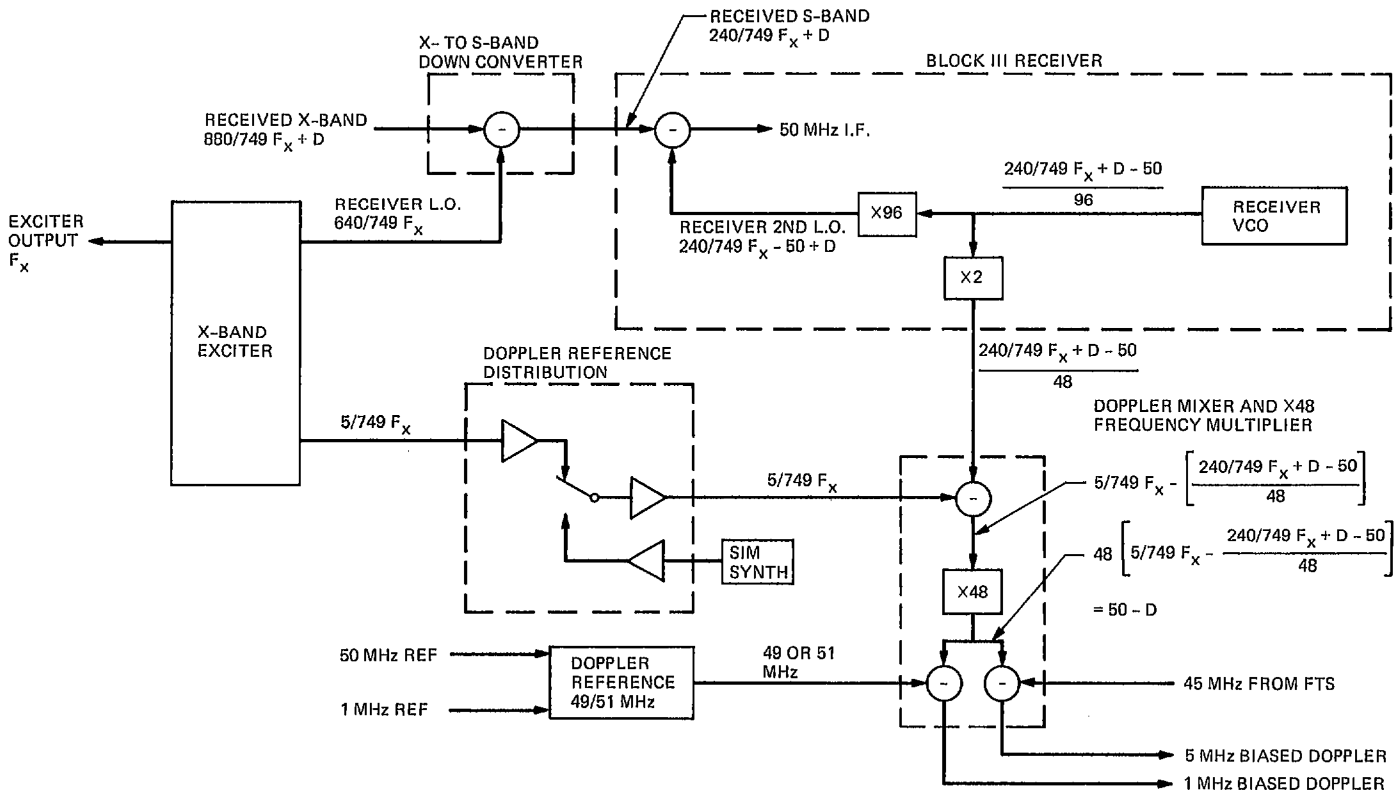


Fig. 6. Block III X-band doppler extraction

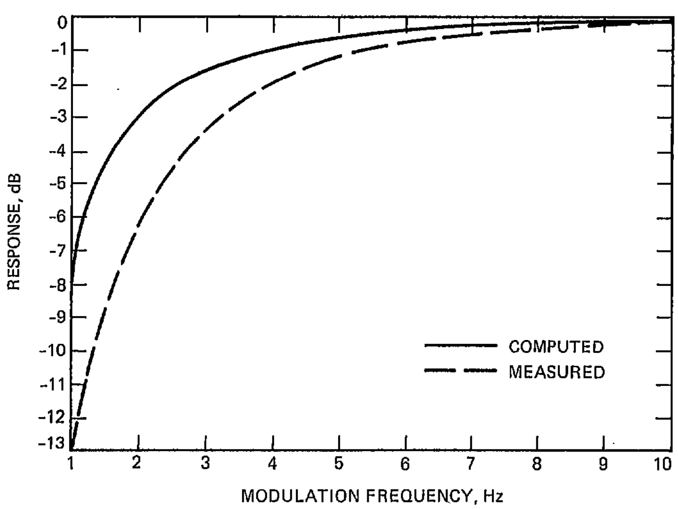


Fig. 7. Command verification loop response

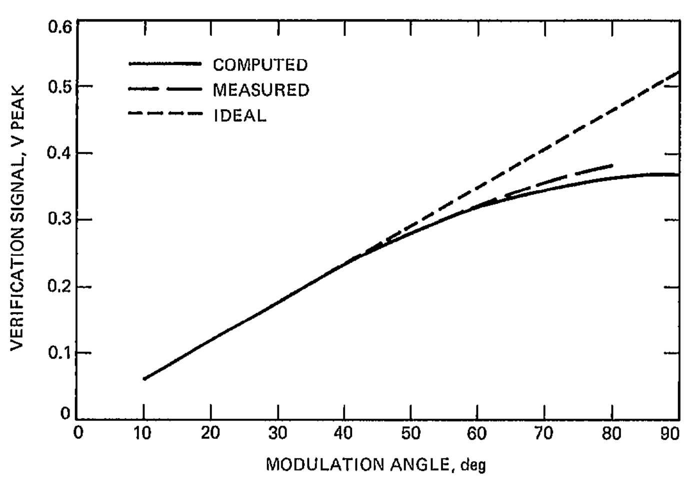


Fig. 8. Command verification level vs modulation voltage