# X-Band Uplink Ground Systems Development

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*The development of new ground equipment for an X-band uplink to supplement the present S-band uplink is underway. The exciter and doppler extractor developments, and the high-power transmitter development with some early test results are presented.*

## I. Introduction

The requirements for increased accuracies of spacecraft navigation as well as charged particle calibrations has prompted the development of an uplink in the X-band region with much improved short- and long-term frequency stabilities.

To provide this stable X-band uplink signal, a new exciter design concept is being used. In addition, an X-band phase modulator is being incorporated to provide broad instantaneous bandwidth to accommodate higher clock frequencies with consequent improved resolution.

The exciter design is discussed in Part II, covering such aspects as the block diagram, expected oscillator frequency stability, effect of instability of the cables between the control room and the antenna, improvement in uplink stability obtained with the transmitter phase control loop, expected frequency stability of exciter references for the doppler extractors, expected performance of the X-band range modulator and the frequency stability improvement to be obtained with temperature control of the hardware environment.

In addition to the exciter and doppler extractor, a 20-kW transmitter is being designed and built for installation at DSS 13, where it will be evaluated for application in the Deep Space Network. A major portion of any transmitter design is the system for protection, monitor, and control of the various subsystems associated with the transmitter. Also, the Monitor and Control System is a major part of overall system reliability. Part III of this article will describe the control system to be used in the transmitter. Also, further evaluation of the VA-876 klystron will be described and the results presented.

## II. Exciter

A simplified block diagram of the exciter is shown in Fig. 1. To generate the 7.2-GHz exciter signal, the 100 MHz from the hydrogen maser frequency standard is multiplied up to 6500 MHz and summed with 700 MHz generated by multiplying the exciter's digitally-controlled oscillator (DCO) by 16. Sixteen is the minimum multiplying factor possible that permits an X-band operating range from 7145 MHz to 7235 MHz. The limitation is the DCO frequency range of 40 to 51 MHz. This method of generating the exciter signal reduces the DCO contribution to the exciter signal stability. To illustrate this, assuming an X-band frequency of 7200 MHz, the input frequencies to the summing junction are 700 MHz and 6500 MHz. Relative to the X-band frequency, the frequency ratios are 700/7200 and 6500/7200. In this configuration, the exciter DCO contributes less than 10 percent of its instability to the X-band signal. Since the stability of the hydrogen maser is considerably better than the exciter DCO, the total exciter stability is improved.

### A. Exciter Oscillator Stability

To establish stability estimates for the X-band exciter, three Dana synthesizers (DCOs) were measured using the same techniques that are used for measuring maser stability (Ref. 1). Figure 2 is a graph showing the stability of the synthesizers for integration periods in excess of 1000 seconds. For comparison, a hydrogen maser stability curve is included.

Figure 3 is a stability curve computed from the data in Fig. 2. The curve shows the resultant X-band stability ($\sigma_{exc}$) when synthesizer B is algebraically added to the maser as shown:

$$\sigma_{exc} = 700/7200 \; \sigma_{DCO} + 6500/7200 \; \sigma_{maser}, \text{ worst case}$$

where the ratios 700/7200 and 6500/7200 are the weighting constants for the contribution of the synthesizer and hydrogen maser to the X-band instability.

### B. 100-MHz Cable Stabilizer

Figure 4 is a simplified block diagram of the complete exciter. The stability of the cable used to transmit the 100-MHz reference frequency from the control room to the antenna is critical. Environmental conditions, such as temperature and mechanical stress, will cause a cable to change electrical length. For the type cable used between the control room and antenna, measurements made at DSS 14 (Ref. 2) showed that the frequency stability ($\Delta f/f$) is approximately $6.6 \times 10^{-15}$.

To improve the stability of the 100-MHz reference signal transmitted through the cable from the control room to the antenna, a cable stabilizer will be used. Lab measurements made on a prototype cable stabilizer indicate a reduction of phase delay change of a factor of 50 can be achieved.

### C. Transmitter Phase Control Loop

The 20-kW X-band klystron proposed for use in the X-band uplink is undergoing evaluation tests (Part III) including the measurement of the amplifier's phase sensitivity to coolant temperature, drive power, beam voltage, etc. To stabilize the phase of the X-band uplink signal, a phase control loop has been incorporated that will reduce the phase perturbations due to the klystron by a factor of 100.

The phase control loop compares the exciter and transmitter outputs in a phase detector, and the error voltage is filtered, amplified, and applied to the control port of an X-band voltage-controlled phase shifter. The signal phase delay through the phase shifter is automatically shifted in the opposite sense of the transmitter variations, thus maintaining a nearly constant transmitter output phase.

The loop parameters were selected for a 3-dB frequency response of 2 Hz to eliminate any possibility of reducing (tracking out) low-frequency command modulation signals. To accommodate future science experiments, a multibandwidth loop can be incorporated.

### D. X-X Doppler Reference Generator

The frequency of the exciter reference required for the doppler extractor must be:

$$a/b \, f_{Tx}$$

where $a/b$ is the coherent DOWN/UP ratio and equals

240/749 for X up and S down

880/749 for X up and X down

It is not practical to generate these frequencies entirely from the X-band output signal due to hardware limitations. An output from the exciter at a lower frequency is required. However, at no point in the exciter mechanization does $f_{TX}/n$ (where $n$ is a whole number) exist. Therefore, this frequency must be generated in some manner.

To accomplish this, the output of the exciter DCO was selected as the reference frequency for generating the doppler reference signal (Fig. 4). Due to the mechanization of the exciter, the DCO output inherently contains a portion of the 6500-MHz reference signal (i.e., $f_{DCO} = f_{Tx}/16 - 6500/16$). To eliminate the 6500/16 term, the DCO output is divided by five to yield a frequency of $f_{Tx}/80 - 1300/16$ and then summed (mixed) with a 1300/16 signal resulting in an output frequency of $f_{Tx}/80$. This frequency is subsequently multiplied by 2096/749 and then again by five to yield 131/749 $f_{Tx}$ which is added to the exciter output frequency to derive the 880/749 $f_{Tx}$ doppler reference.

The stability of the doppler reference, like the exciter, is a weighted combination of the exciter DCO and the 100-MHz maser signals. The worse case exciter stability was shown to be:

$$\sigma_{EXCIT} = 700/7200 \; \sigma_{DCO} + 6500/7200 \; \sigma_{MASER} \quad (1)$$

and the X-X band doppler reference stability is:

$$\sigma_{X-X} = 131/749\ \sigma_{EXC} + \sigma_{EXC} \tag{2}$$

Substituting Eq. (1) into Eq. (2), the doppler reference stability is found to be:

$$\sigma_{X-X} = 0.114\ \sigma_{DCO} + 1.061\ \sigma_{MASER}$$

### E. X-S Band Doppler Reference

The doppler reference for the X-S band doppler extractor is generated in a similar manner as the X-X band reference (Fig. 4). The $f_{Tx}/80$ signal is multiplied by 8144/749 and then by 5 to obtain a frequency of 509/749 $f_{Tx}$. This frequency is subtracted from the exciter output to yield the 240/749 $f_{Tx}$ doppler reference. The S-X doppler reference stability is determined by

$$\sigma_{X-S} = \sigma_{EXC} - 509/749\ \sigma_{EXC} \tag{3}$$

Again, by substituting Eq. (1) into Eq. (3), the X-S band doppler stability is

$$\sigma_{X-S} = 0.03115\ \sigma_{DCO} + 0.2893\ \sigma_{MASER} \tag{4}$$

### F. X-Band Phase Modulator

To accommodate higher ranging clock frequencies for improved navigation, an X-band phase modulator is being utilized in the exciter. The instantaneous bandwidth is 90 MHz, established by a bandpass filter. The modulator can be modulated with frequencies up to 10 MHz. Two modulation ports are available to allow range and command signal inputs.

### G. Coherent Test Signals

Coherent receiver test signals are generated in the same manner as the X-X and X-S doppler reference signals, with the exception that the test signals can be phase modulated by means of the X-band phase modulator. To accomplish this, the modulated X-band signal is summed with the 131/749 $f_{Tx}$ and the 509/749 $f_{Tx}$ outputs. The levels of the test signals can be varied, by means of programmable step attenuators (not shown in Fig. 4), to facilitate receiver calibration and testing.

### H. Equipment Temperature Stabilization

To assure long-term stability of the antenna-mounted exciter equipment, all of the RF hardware will be packaged in temperature-stable enclosures. Based on stability measurements made on Block IV R/E RF modules, it is conservatively estimated that the temperature-controlled exciter equipment will contribute $0.26 \times 10^{-15}$ to the total exciter instability.

## III. High-Power Transmitter

A DSN transmitter generally consists of four major components separated by considerable distances. These components are the Power Amplifier Assembly, the Heat Exchanger, the Power Supply, and the Control Panel. It is a requirement that the Power Amplifier Assembly be mounted near the antenna feed, while the Heat Exchanger and Power Supply are mounted on the ground. The Control Panel is mounted near the operator position in the control room. A further requirement of the X-band uplink transmitter is that it be compatible with unattended operation and DSN Station automation. Figure 5 illustrates a typical Transmitter System.

A major problem with high-power circuits distributed over a large area is induced noise in the form of ground loops and in inductive pick-up of extraneous signals, while well-shielded multiconductor cables are bulky and expensive.

### A. Control System

The planned Control System for the X-band uplink transmitter will incorporate the following features:

(1) Each component will respond to high-level commands and contain sufficient control and protective circuitry to prevent damage to that component.

(2) Communications between components will be by means of a single serial data circuit.

(3) Control hierarchy will minimize communications between components.

(4) Protection of hardware and personnel will not rely on Control System software.

(5) Commercially-available equipment will be used in the Control System to the maximum extent possible

Figure 6 is a block diagram of the Control System for the X-band uplink transmitter. By using a serial data stream and minimizing communications between transmitter components, it will be possible to economically use techniques for noise reduction such as error-checking and error-correcting codes, filtering, low data rates, and isolation schemes such as fiber-optic communications. To meet the protection requirements (item 4), a hard-wired safety interlock between transmitter components will be incorporated. Since sufficient fast protection circuitry will be incorporated in each component, this intercomponent interlock will not be required to operate at high speed (ten millisecond response will be adequate).

There is at present a wide variety of commercially-available Control System hardware that is compatible with other manufacturers, so that it will be economical to utilize this type of hardware. In particular, there are industrial-grade control modules designed to interface to high-power parts, such as contactors, meters, relays, etc. with a minimum of mechanical and electrical design. Figures 7 and 8 show an example of this type of industrial control equipment that will be incorporated in the design.

### B. Klystron Evaluation

The signal source for driving the klystron at the Microwave Test Facility had poor short-term phase stability (Ref. 3), so a Hewlett-Packard Model 5065A Rubidium Frequency Standard, a Hewlett-Packard Model 5100A Frequency Synthesizer, and a modified California Microwave, Inc., Model PE84PL-109 X75 Frequency Multiplier was installed as a new signal source (Fig. 9), replacing the HP Model 620A Signal Generator described in the reference. Figure 10 illustrates the short-term stability improvement of the X-band drive chain.

Using the test configuration of Fig. 9, 500-s stability tests were conducted (Fig. 11). Since the klystron phase delay is most sensitive to beam voltage, this parameter is also recorded on the chart.

The VA-876P klystron has been tuned to operate over the full transmitter design range (7145-7235 MHz) with no degradation in performance. The klystron has shown no instabilities or erratic performance during these tests. Figures 12 and 13 show the passband response at both high and low limits of the DSN frequency band.

Figure 14 shows the phase change across the klystron as a function of frequency. This parameter is sometimes referred to as "Group Delay" and is used as a measure of the electrical length of the klystron. Using the values from Fig. 14, the group delay of the VA-876P klystron at midband is 44 ns. The period of the center frequency (7190 MHz) is 0.139 ns, giving an electrical length of the klystron of $1.14 \times 10^5$ electrical degrees.

As of this reporting, Varian Klystron Model VA-876P S/N 344 has operated 692 filament hours and 545 beam hours. The test bed transmitter has operated the klystron through a total of 155 on/off cycles.

## IV. Conclusions

The design of the X-band exciter and the transmitter control system have been presented. Techniques were incorporated into the exciter design to assure good short- and long-term frequency stability. From data and conservative estimates, the overall exciter and doppler reference stabilities will be approximately $2.5 \times 10^{-15}$ for 1000-s integration periods. The 20-kW X-band klystron tube continues to operate satisfactorily and data is being obtained that will permit analysis and prediction of overall system performance.

A future article will describe the complete X-band uplink scheme including the receiver and doppler extractor mechanization and their expected stability factors.

## References


1. Kuhnle, P. F., "Hydrogen Maser Implementation in the Deep Space Network at the Jet Propulsion Laboratory," to be published.
2. Clements, P. A., "Electrical Length Stability of Coaxial Cable in a Field Environment," Technical Report 32-1526, Vol. VII, pp. 97-100, Jet Propulsion Laboratory, Pasadena, Calif.
3. Kolbly, R. B., "Evaluation of the VA-876P Klystron for the 20-kW X-Band Uplink Transmitter," *The Deep Space Progress Report 42-54*, pp. 41-50, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 1979.

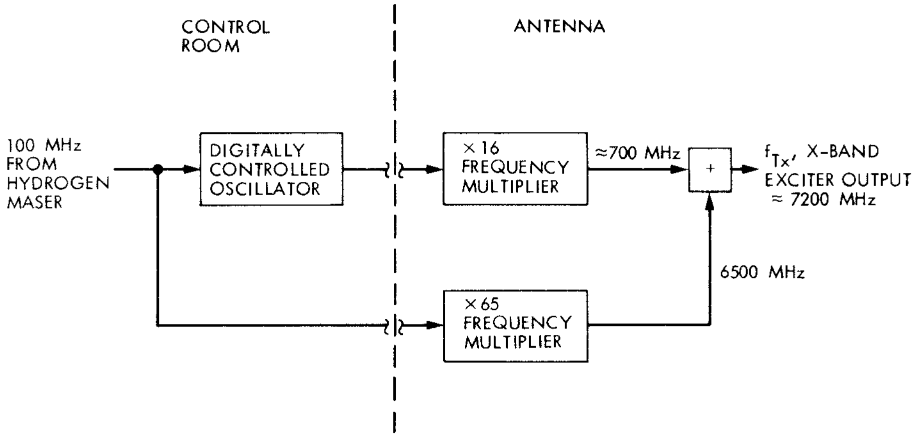


**Fig. 1. Simplified block diagram of the basic exciter mechanization**

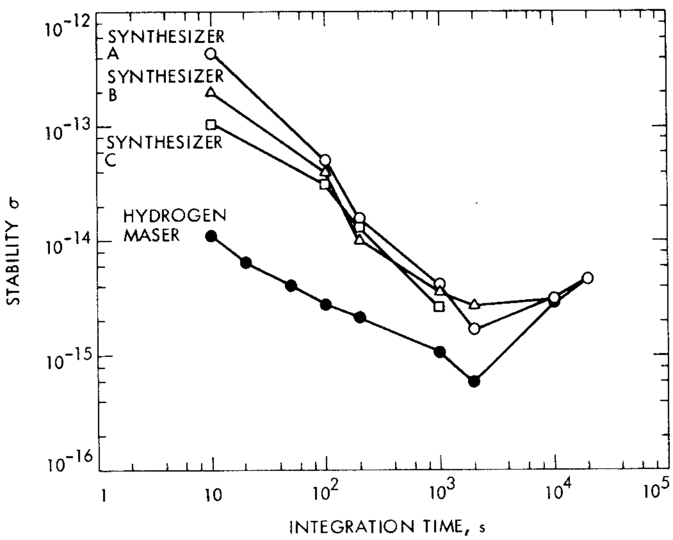


**Fig. 2. Measured frequency stability of Dana synthesizers and hydrogen maser**

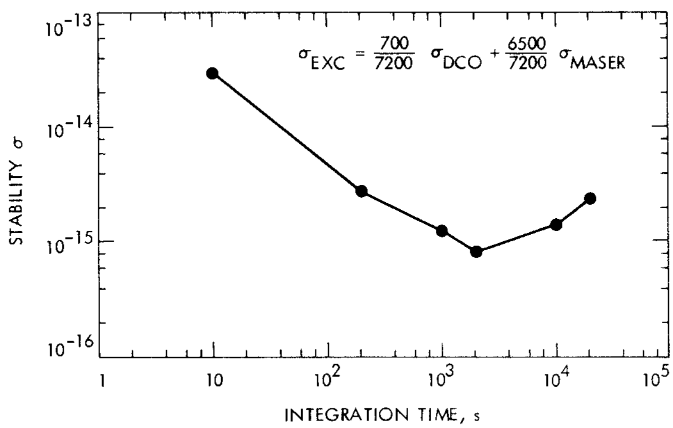


**Fig. 3. Combined frequency stability of a Dana synthesizer and hydrogen maser**

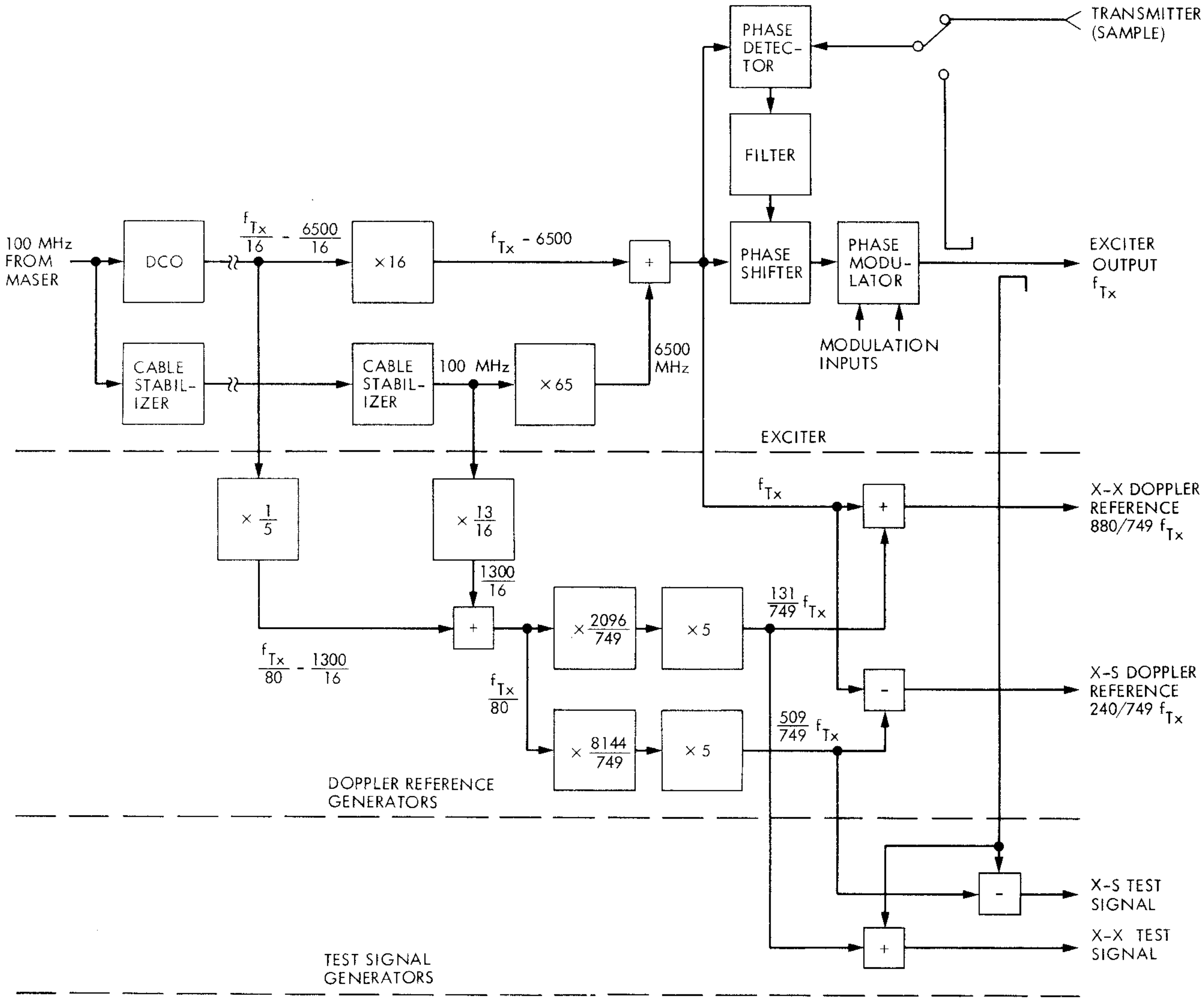


Fig. 4. Block diagram of the complete exciter

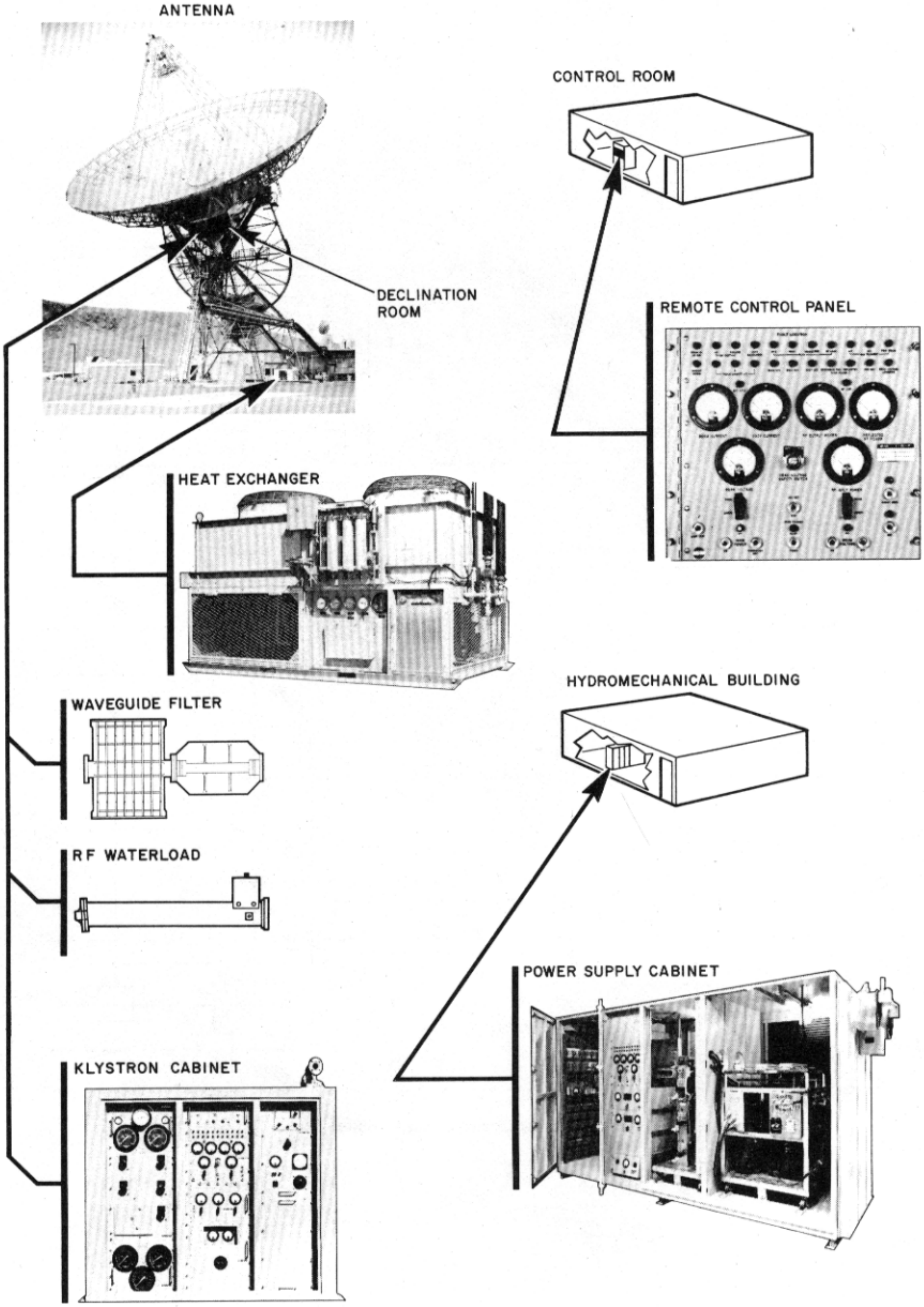


**Fig. 5. Typical DSN transmitter subsystem**

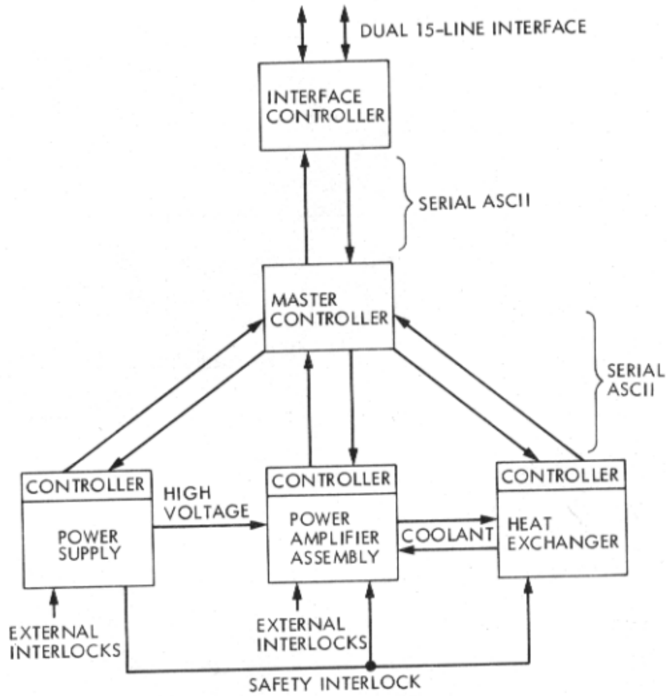


Fig. 6. Block diagram of transmitter control system

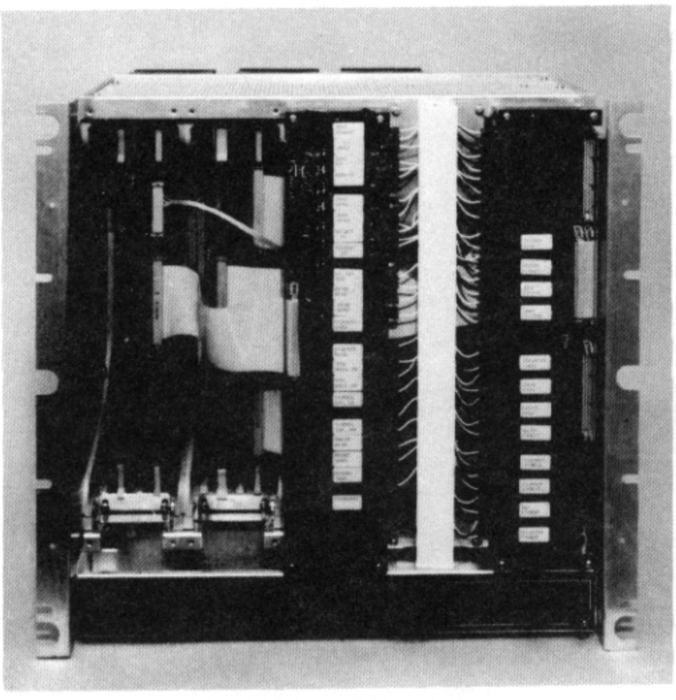

Fig. 7. ICS-80 chassis, front view

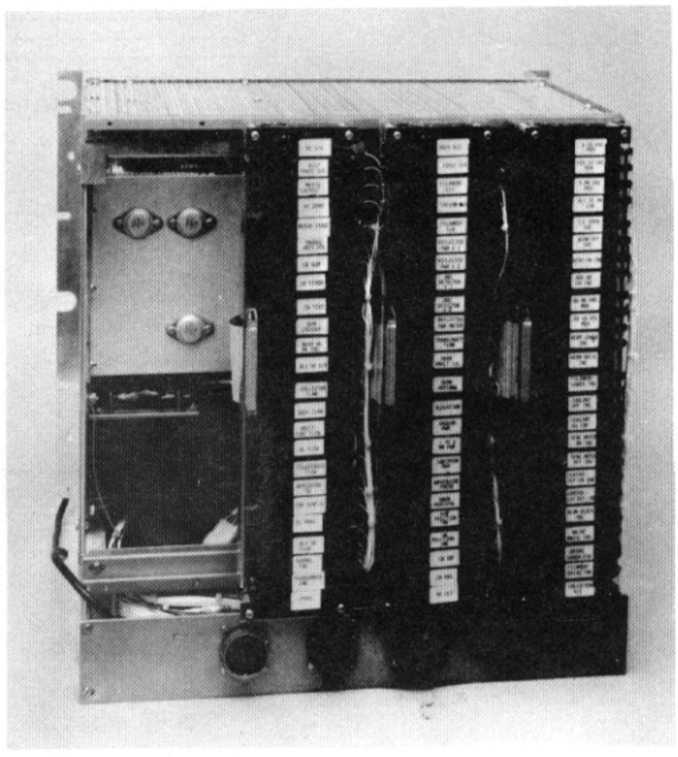

Fig. 8. ICS-80 chassis, rear view

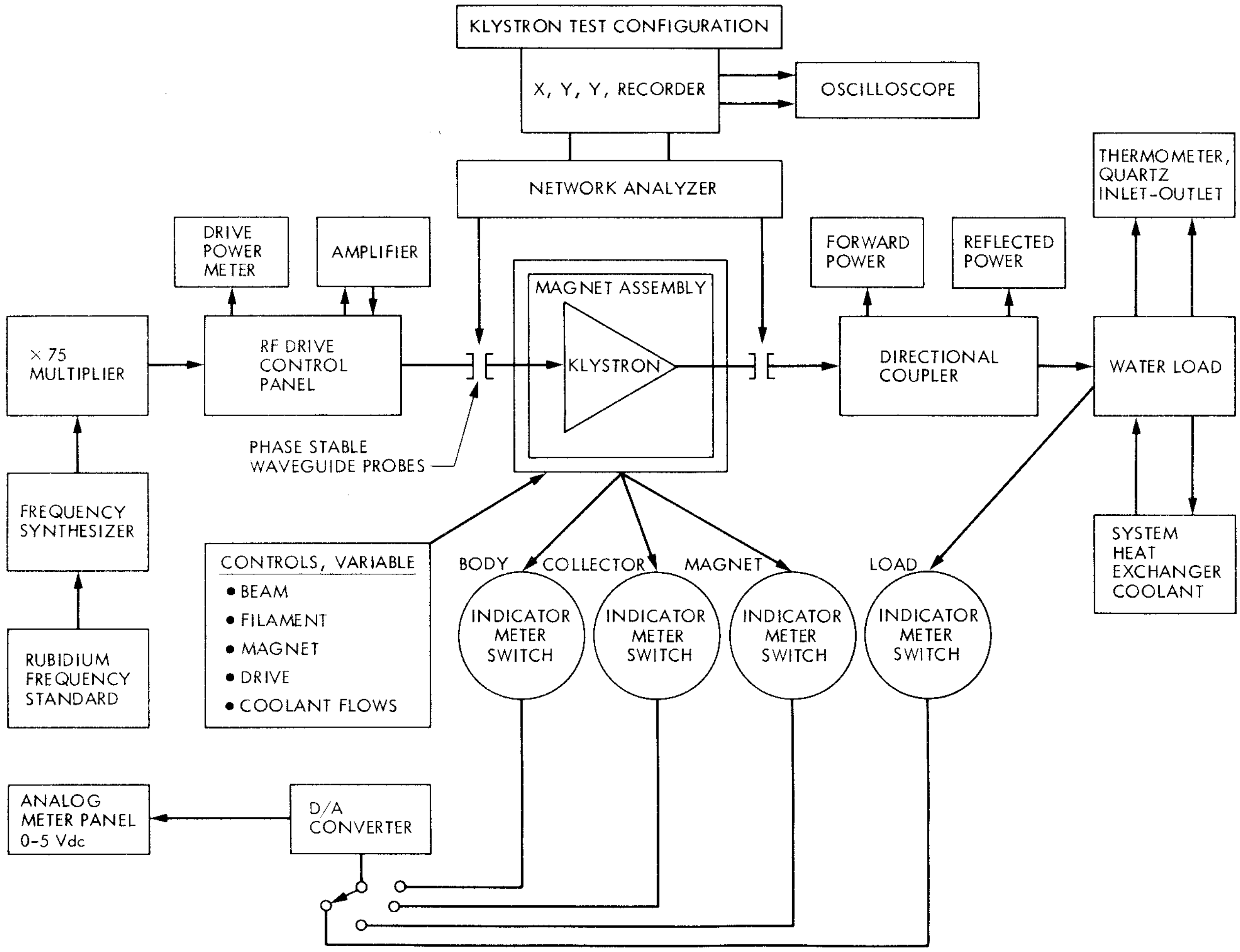


**Fig. 9. Klystron test configuration**

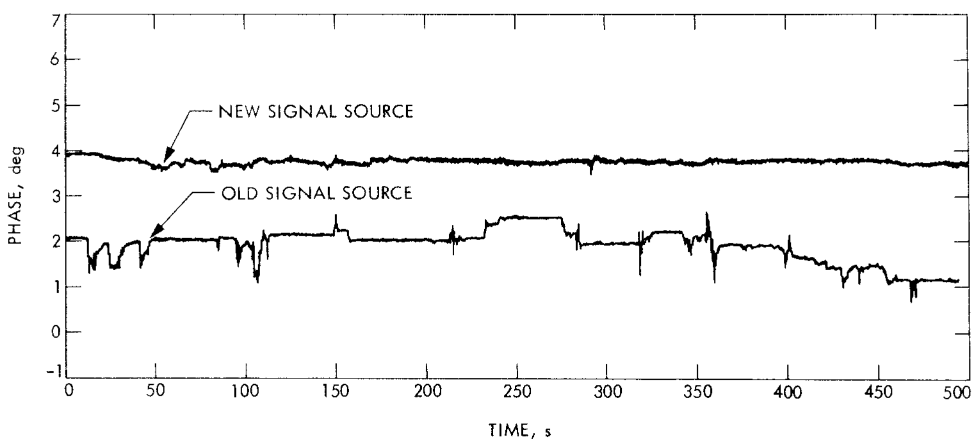


**Fig. 10. Stability comparison of old and new signal sources**

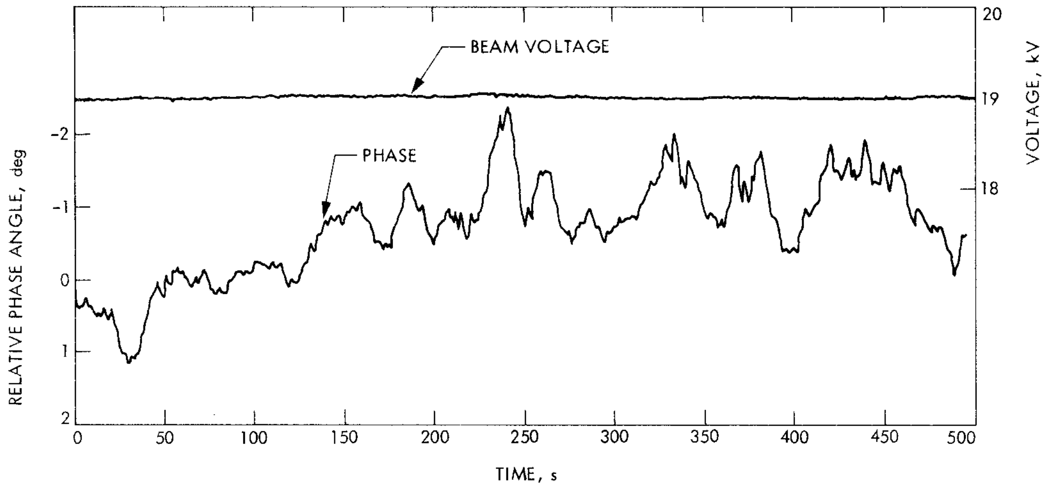


**Fig. 11. Klystron stability test**

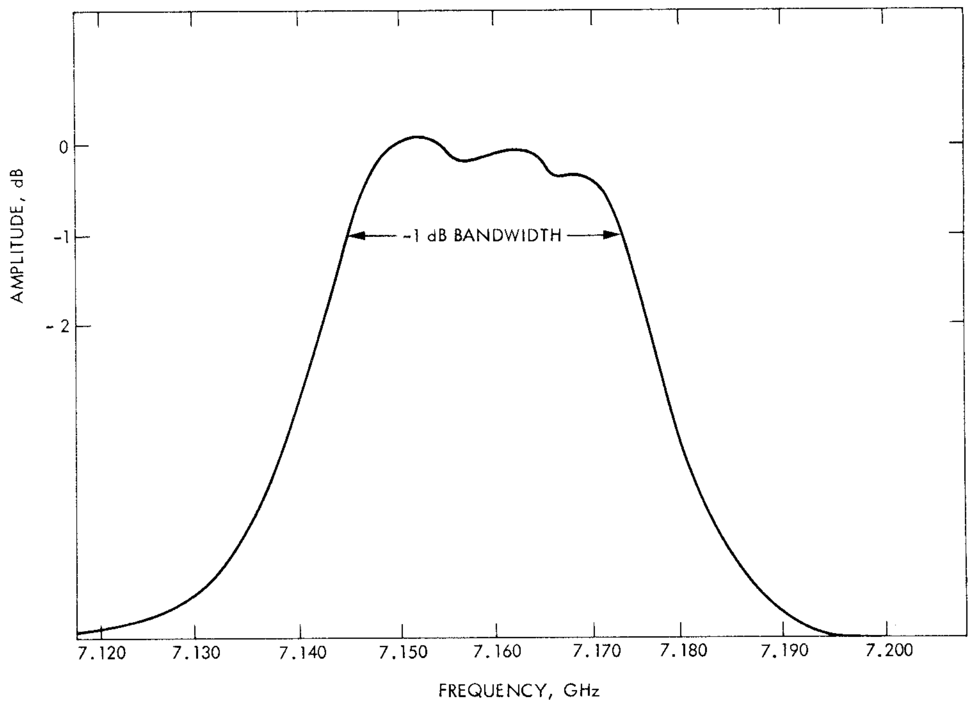


**Fig. 12. Klystron bandwidth, tuned for lower band**

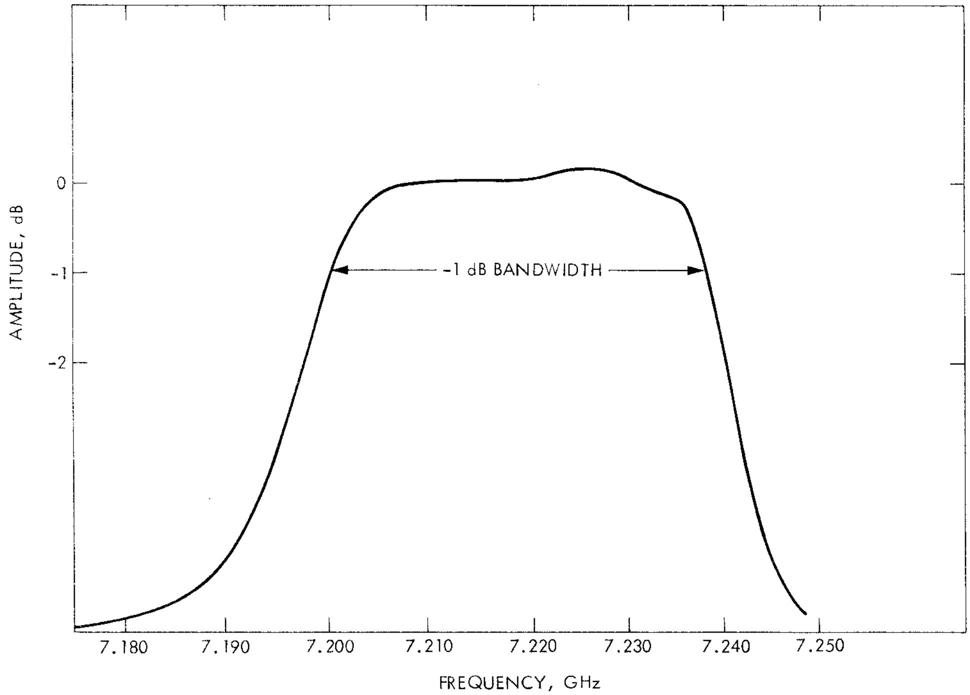


**Fig. 13. Klystron bandwidth, tuned for upper band**

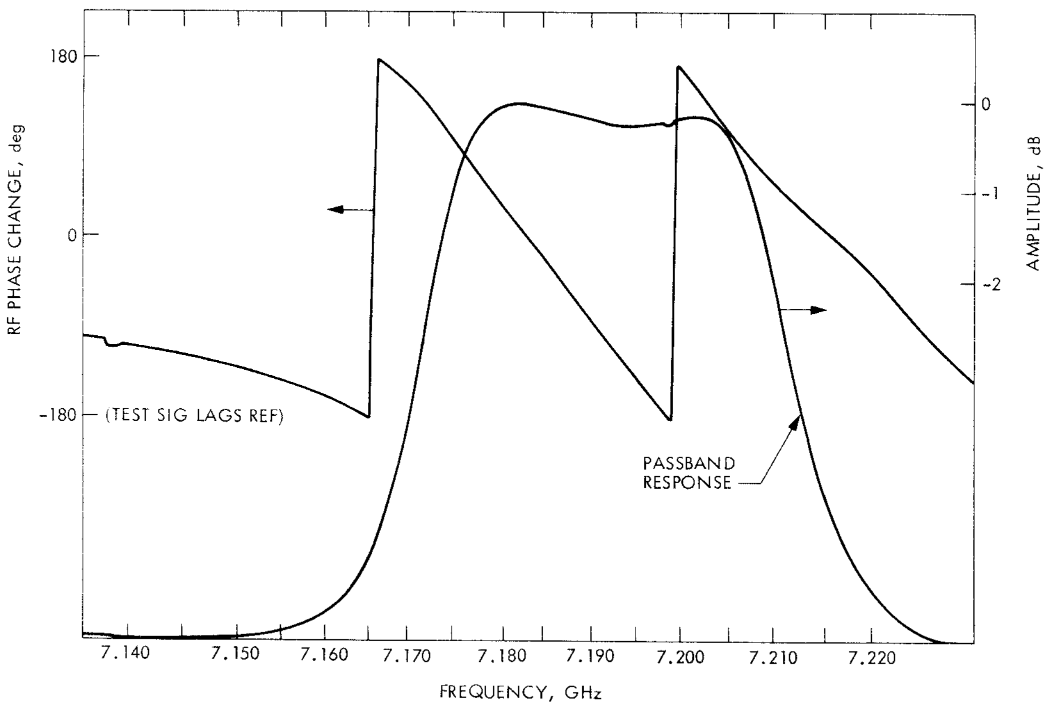


**Fig. 14. Klystron RF phase change vs frequency**