Chapter 2
Characteristics

2.1 INTRODUCTION

The Model 5207 (single-phase) and the Model 5208 (two-phase) are computer-controllable instruments. Integral RS232C and IEEE-488 interfaces allow total programmability of either model. Computer-controllable functions include sensitivity, averaging time constant, phase, operating frequency, offset, dynamic reserve, display mode, and others. Other standard features include auto-phasing, auto-ranging, and "sine-wave" response.

Both instruments incorporate an autofunction capability that can:

1. **Auto-Set:** Automatically adjust their fullscale sensitivity and phase to match the signal of interest.

2. **Auto-Normalize:** Set a given output amplitude to represent 100% of full scale. Subsequent measurements are then quantified with respect to the full-scale level thus established.

3. **Auto-Offset:** Automatically supply dc offset so that the output resulting from some given signal level is adjusted to zero.

4. **Auto-Range:** Automatically adjust full-scale sensitivity to maintain maximum output.

5. **Auto-Ratio:** Compute the ratio of X, Y, or R to AUX or the LOG of (R/AUX). Ratio is displayed and provided at rear- panel connector. **Note:** In Model 5207, ratio of X/AUX only is provided.

Both units incorporate digital and analog displays. A large four digit display presents measurement results conveniently in terms of voltage, dB's, degrees, or ratios. Also displayable are operating parameters such as the internal-oscillator frequency, the amount of dc output suppression, and the phase shift. An analog meter augments the digital display to allow trend following; a second analog meter on the Model 5208 also allows simultaneous read-out of additional information. The two mixer channels of the Model 5208 allow it to simultaneously measure the in-phase (X) and quadrature (Y) components of a signal, or to measure the resultant magnitude and phase angle, all with respect to the applied reference. All display functions are under pushbutton control.

Moreover, all processing, display modes, and commands associated with the front-panel pushbuttons can be controlled by a computer through the digital interface.

Advanced technology has been used in these instruments to provide excellent performance and convenience. For example, "sine-wave" or harmonic-free response at higher operating frequencies is achieved without degrading the specifications for dynamic reserve and dc output stability. Design innovations in the Model 5207/8 allow three band-determining cards to be housed simultaneously to achieve an operating frequency range of 5 Hz to 200 kHz (0.5 Hz optional). A front-panel pushbutton allows convenient selection of the operating band.

Lock-in amplifiers are now the keystone of many analytical and control systems. They are almost a necessity for recovering amplitude and phase information for signals overwhelmed by noise and interference. Together with associated accessories such as light choppers and waveform recorders, these new programmable lock-in amplifiers offer a new sophistication and freedom to both research and industry. With their versatility, precision, and measuring power, both the Model 5207 and the Model 5208 should prove invaluable wherever signal amplitude and phase characteristics are to be measured under difficult conditions.

2.2 SPECIFICATIONS

2.2A SIGNAL CHANNEL

FULL-SCALE SENSITIVITY

1. **Model 5207:** 1 µV to 5 V rms, 1-2-5 sequence. x 10 output expansion increases the maximum full-scale sensitivity to 100 nV.

2. **Model 5208:**

Channel 1: Same as for Model 5207.

Channel 2: 1 μV to 5 V rms, 1-2-5 sequence.

Input Impedance: AC coupled, 100 MΩ shunted by 40 pF. Input Connector shell is 10 Ω above chassis ground. Current-input preamplifiers (Models 181 and 5002) are available.

Input Modes: Single-ended (A), or differential (A-B).

Maximum dc Input: 100 V; >10 V ac will damage input; saturation occurs at 5 V rms out of pass band.

Frequency Range: The frequency range is determined by plug-in cards, one for each of the three ranges, **Broadband (BB)**, **Audio Frequency (AF)**, and **Low Frequency (LF)**. One, two, or all three of these cards can be installed. A front-panel switch selects the "active" range. The limits for each range are:

BAND	OPERATES OVER
BB	5Hz-200 kHz*
AF	5 Hz-20 kHz*
LF	5 Hz-2 kHz*

*The lower limit is 5 Hz (standard) or 0.5 Hz (optional). Because the response time of the 0.5 Hz option is much slower, users are advised to purchase the 5 Hz lower limit unless they intend to operate below that frequency.

Figures 2-1, 2-2, and 2-3 show the effect the choice of F BAND has on the pre-PSD (phase sensitive detector) characteristics of the instrument. Figure 2-5 shows the I.F. Amplifier response.

Internal Noise (shorted input): Typically 5 nV per root Hz, at 1 kHz; 20 nV rms per root Hz at 10 Hz. See Figure 2-4 for typical noise-figure contours.

Common-Mode Rejection Ratio (CMRR): 120 dB maximum from 60 Hz to 1 kHz with 6 dB/octave rolloff above 1 kHz.

Common-Mode (Max): 5 V rms (differential + common mode)

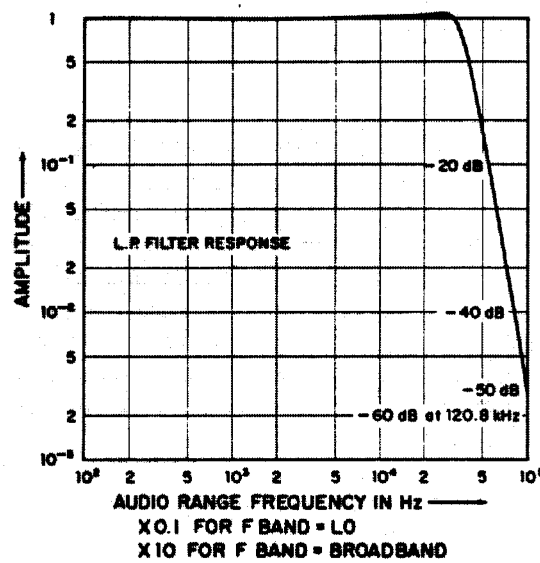


Figure 2-1. TYPICAL LOW-PASS FILTER RESPONSE AS A FUNCTION OF F BAND

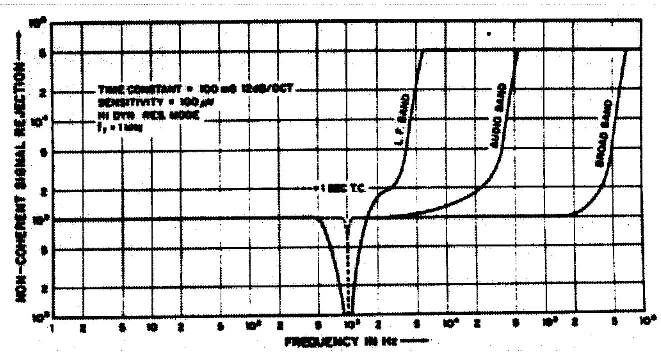


Figure 2-2. TYPICAL NOISE REJECTION AS A FUNCTION OF F BAND

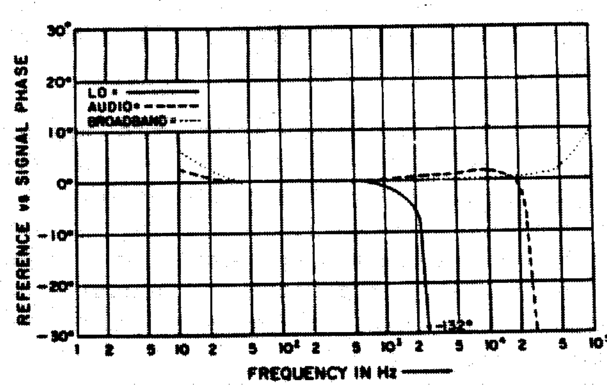


Figure 2-3. TYPICAL PHASE SHIFT AS A FUNCTION OF F BAND (STANDARD I.F.)

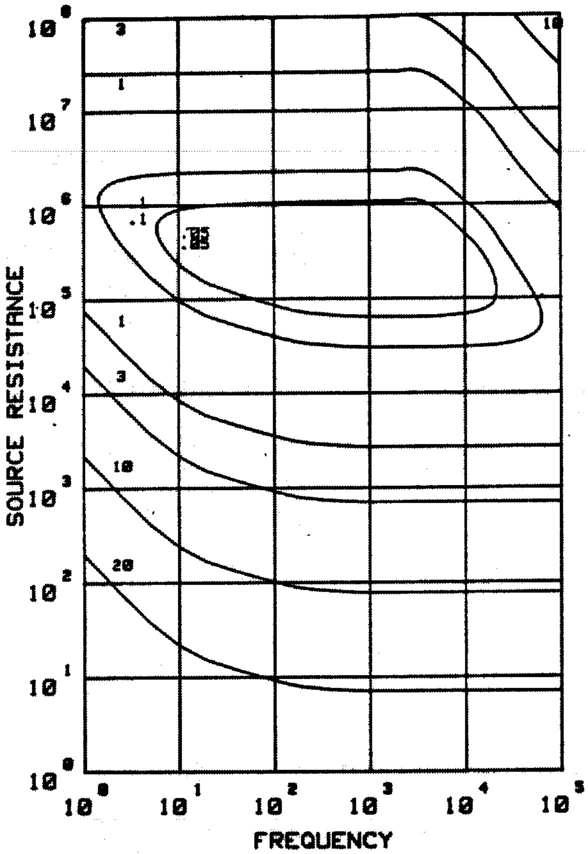


Figure 2-4. TYP. NOISE-FIGURE CONTOURS

Gain Stability: ±200 ppm/°C; ±200 ppm/24 hours.

Dynamic Reserve:* Three different levels can be selected, as follows.

1. **High Stability:** 20 dB
2. **Normal:** 40 dB
3. **High Reserve:** 60 dB

The Input low-pass filter (BB, AF, LF) can provide as much as 36 dB of additional reserve. Crystal Het™, if present (/97 Option) can add as much as 14 dB. The total reserve cannot exceed 96 dB.

I.F. Filter Response: Standard response depicted in Figure 2-5A. Crystal-Het™ response is depicted in Figure 2-5B. Crystal-Het™ provides a 100 Hz bandwidth at 1 MHz (Q = 10000).

2.2B REFERENCE CHANNEL

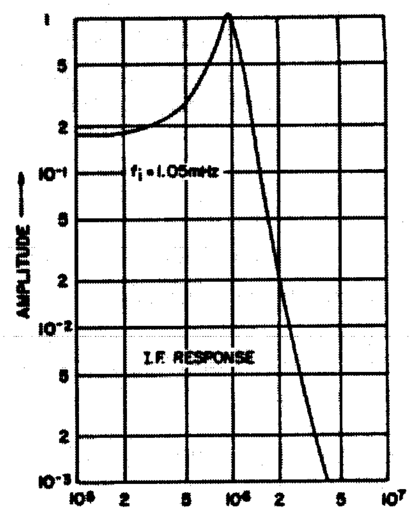
Frequency Range: 5 Hz to 200 kHz (0.5 Hz option available).

Modes:

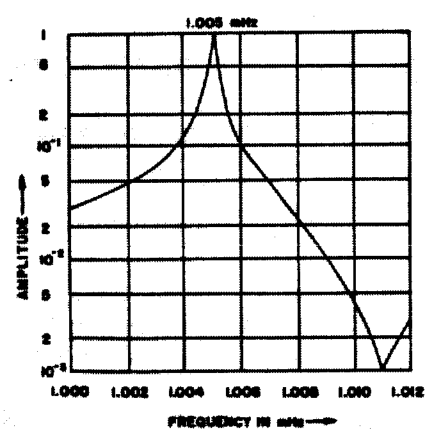
1. **External:** Reference locks onto and tracks the external reference signal. There are two variations of this mode. "F", in which demodulation occurs with respect to the reference frequency, and "2F", in which demodulation occurs with respect to twice the reference frequency. Critical reference channel parameters are:

Input Impedance: 10 MΩ shunted by 30 pF.

Waveform Requirements: Signal that crosses its mean twice (only) in each cycle.



A: Standard Unit



B: With Crystal-Het™ Filter Option

Figure 2-5. TYP. I.F. AMPLIFIER RESPONSE

Amplitude Requirement: 100 mV to 1 V rms recommended. Reference Low light indicates insufficient amplitude. Mean to peak level should not exceed 5 V.

Tracking Rate:

Above 100 Hz: <1 s/decade

Below 100 Hz: <10 s/decade

<100 s/decade with 0.5 Hz option

Internal Mode: Instrument must be equipped with Internal Oscillator (/94 Option). Reference channel is driven at the frequency (2 Hz to 100 kHz) of the internal oscillator.(Oscillator specs. in Subsection 2.2G)

Phase-Shift Characteristics

1. **Phase Shift:** 0°, 90°, 180°, & 270° plus vernier with 0.025° resolution.

2. **Phase Noise:** 5 millidegrees rms at 1 kHz, 100 ms time constant (12 dB/octave).

3. **Phase Error:** Less than 1° above 10 Hz. This phase specification holds to:

   BROAD BAND: 50 kHz
   AUDIO FREQUENCY: 5 kHz
   LOW FREQUENCY: 500 Hz

4. **Orthogonality:** (Model 5208):90° +0.5°.

2.2C PHASE-SENSITIVE DETECTORS

Dynamic Reserve, Output Stability, and Sensitivity:

Reserve	Stability	Sensitivity
20 dB	20 ppm/°C	100 µV to 500
40 dB	100 ppm/°C	10 µV to 50 mV
60 dB	1000 ppm/°C	1 µV to 5 mV

Table 2-1. RESERVE VS OUTPUT DRIFT

Input Low-Pass Filter (LF, AF, BB) can give as much as 36 dB of additional dynamic reserve. Crystal-Het™ can add an additional 14 dB. X10 Expand ON gives an additional 20 dB.

Time Constants: 1 ms to 100 s in 1-3-10 sequence; 6 or 12 dB/octave; True 12 dB/octave for all time-constant settings.

Zero Suppression: The signal in the Model 5207, and the Channel 1 signal ("X" and "R") in the Model 5208, can be offset as follows.

1. X10 Expansion OFF: ±1 x full scale.

2. X10 Expansion ON: ±10 x full scale.

Harmonic Rejection (typical): 55 dB

2.2D MODEL 5207 OUTPUTS

Analog Meter:

1. Signal Output

2. Signal Output + offset setting

Digital Meter (4 digits plus polarity):

1. Signal Output

2. Signal Output + offset setting

3. Internal-oscillator reference frequency

4. Phase Shifter

5. Zero Suppress

6. Auxiliary outputs from plug-in options

7. Error Messages

8. Ratio of signal output to auxiliary input

Output BNC: Output of ±10 V corresponds to full-scale input; 600 Ω output impedance.

Ratio Output BNC: Rear panel, ±10 V, 1000 Ω. Output is the ratio of X to AUX. The maximum input levels to the multiplexed 12-bit ADC are ±10 V, corresponding to ±2048 counts. Input ratios can span three orders of magnitude, 10:1 to .01:1.

2.2E MODEL 5208 OUTPUTS

Analog Meters:

1. Channel 1:

   a. "X" (in-phase signal component).

b. "R" (resultant or magnitude of signal).

c. Log R (dB reading of signal magnitude relative to full scale; 0 to -60 dB useful range).

2. Channel 2:

a. "Y" (quadrature signal component).

b. θ (phase shift of signal relative to reference at mixer input)

Digital Panel Meter:

1. "X", "Y", "R", log R (dB reading of signal magnitude relative to full scale; 0 to -60 dB useful range). Also, AUX, X/AUX, Y/AUX, R/AUX, or LOG (R/AUX), where AUX is voltage applied to rear-panel AUX-IN connector or output of plug-in module.

2. Phase shifter settings.

3. Internal-oscillator reference frequency.

4. Channel 1 offset or Zero Suppress

5. Error Messages.

BNC Connectors

1. **Ch 1 and Ch 2:** Connectors parallel corresponding analog meters; full scale = ±10 V dc, 600 Ω output impedance. During log R operation, the calibration factor is -10 dB/volt (-60 dB max.). Phase readings are calibrated as ±50 mV/degree (±9 V max).

2. **Ratio Output BNC:** Rear panel, ±10 V, 1000 Ω. Output is the ratio of X/AUX, Y/AUX, R/AUX, or LOG(R/AUX), where AUX is voltage applied to rear-panel AUX-IN connector or output of plug-in module. The maximum input levels to the multiplexed 12-bit ADC are ±10 V, corresponding to ±2048 counts, with a conversion error of ±1 count. Input ratios can span three orders of magnitude, 10:1 to .01:1.

2.2F DIGITAL INTERFACE

Allows the lock-in amplifier to communicate with a system via both IEEE-488 and RS232C data links.

Functions Controlled: Sensitivity, expand, time-constant, phase, reference mode, internal oscillator frequency, dynamic reserve, frequency-range card, zero offset, autofunctions, display selection, and all other front-panel settings.

2.2G MISCELLANEOUS

Overload Indicator Lights:

1. **Model 5207:** Signal pre-mixer channel and output.

2. **Model 5208:** Signal pre-mixer channel, "X" (in phase) output, and "Y" (quadrature) output.

Automatic Functions:

1. **Autorange:** Provides automatic and continuous ranging of ac and dc gain.

2. **Autoset:** Automatically sets the 5208 initial phase and sensitivity. The phase setting can be read on the digital display.

3. **Auto-Offset:** Sets the output voltage to zero and holds the offset. The offset value may be read on the digital display.

4. **Auto-Normalize:** The output voltage is normalized to full scale when this function is selected. Subsequent readings are, therefore, referred to full scale, and the display annunciation is switched off.

5. **Auto-Ratio:** The instrument computes the ratio of X, Y, or R to AUX (voltage applied to rear-panel connector, or output of "plug-in" module). Ratio is displayed and provided at rear-panel connector. **Note:** In Model 5207, ratio of X/AUX only is available.

Auxiliary Power Output: ±15 V, 50 mA for remote or plug-in preamplifier. This connector mates with a Switchcraft #05BL5M or equivalent connector. The EG&G PARC part number for this Switchcraft connector is 2102-0171.

Operating Temperature Range: 10°C to 40°C.

Power Requirements: 95-130 V ac, 60 Hz; 190-260 V ac, 50 Hz; 60 watts.

Size: 17-1/2" Wx22" Dx5-1/4" H (44.5 x 55.9 x

13.3 cm).

Weight: 25 lb (11.3 kg).

Chassis Plug-In Options:

1. **Internal Oscillator** (5207/94 & 5208/94):

   a. **Frequency Range:** 0.1 Hz to 100 kHz controllable by front-panel pushbuttons and external computer via the IEEE-488 or RS232C ports. The selected frequency can be displayed on the front-panel digital meter.

FREQ. RANGE	RESOLUTION
0.1 Hz to 1 Hz.	.01 Hz
1 Hz to 10 Hz	0.1 Hz
10 Hz to 100 Hz	1 Hz
100 Hz to 1 kHz.	10 Hz
1 kHz to 10 kHz.	100 Hz
10 kHz to 100 kHz	1 kHz

   b. **Frequency Stability:** Typically ±500 ppm/°C above 10 Hz.

   c. **Amplitude Stability:** Typically ±0.1%/°C.

   d. **Output Impedance:** 600 Ω

   e. **Second Harmonic Distortion:** 0.5% at 10 Hz; 0.3% at 1 kHz

   f. **Amplitude:** Rear-panel potentiometer allows adjustment of 0 to 5 V rms.

2. **Plug-In Cards**

   a. **Broadband** (Models 5207/97 and 5208/97): See Signal Channel FREQUENCY RANGE specifications.

   b. **Audio Frequency** (Models 5207/98 and 5208/98): See Signal Channel FREQUENCY RANGE specifications.

   c. **Low Frequency** (Model 5207/99 and 5208/99): See Signal Channel FREQUENCY RANGE specifications.

Other Options

1. **I.F. Options**

   a. **/92 Standard IF:** Standard I.F. characteristic is a non-charge option. Response depicted in Figure 2- 5A. Instrument must be purchased with either /92 or /93 option.

   b. **/93 Dual Band IF:** Both standard and crystal I.F. characteristics are provided in units equipped with this option (see Figure 2-5). Characteristic is selectable from front panel.

   c. **Notch Filter:** A field-installable notch filter (Model 5015) is now available. This filter provides a 40 dB notch at 50 Hz or 60 Hz. It can be used to facilitate measurements where high-level, power-frequency interference is a problem. Note that the filter is neither front-panel nor computer controllable.

   d. **Current Sensitive Preamplifiers:** Two different units, the Model 181 and the Model 5002 (plug-in) are available. Contact the factory or the factory representative in your area for additional information.

2.3 DESCRIPTION

2.3A INTRODUCTION

The Model 5207/8 is a heterodyning lock-in amplifier. Input signals at the reference frequency are mixed with an internally developed signal derived from the reference signal. The resulting sum and difference frequency signals are applied to a quasi-resonance filter to remove the upper side-band. The difference frequency is then processed as the information signal. This approach allows the use of narrow-band fixed frequency filters while still allowing operation over a wide frequency range. The functioning of the 5207/8 is discussed in greater detail in the following paragraphs, which are keyed to Figure 2- 6, a simplified block diagram of the 5208. This figure can be readily adapted to the 5207 by simply deleting those blocks that denote functions provided in the 5208 but not in the 5207.

2.3B SIGNAL CHANNEL

Input signals are first applied to an internal preamplifier. This circuit, together with the accompanying gain switching amplifiers and attenuators, buffers the signal and helps set its amplitude at the input to the signal mixer.

Next is the low-pass filter. Its purpose is to pass all signals in the passband of the selected frequency range, while very sharply attenuating signals above the pass-band of the range.

The low-pass filter is followed by some more gain switching circuits. Their output, which includes the signal of interest at the reference frequency, f_r, together with noise and interference, is applied to one input of the Signal Mixer. The output of the Reference Channel is applied to the mixer's other input. The signal is at $f_r + f_i$, where f_r is the reference frequency and f_i is the intermediate frequency (i.f.). The Signal Mixer has the sum $[f_r + (f_r + f_i)] = 2f_r + f_i$ and difference $[f_r - (f_r + f_i)] = f_i$ frequencies as its output. The sum frequency is removed by the following I.F. Amplifier, which, as shown in the figure, has a quasi-resonance response. Below the resonant frequency, the response rolls off steeply to provide a great attenuation of frequencies above f_i. The effect is to further reduce the noise bandwidth, thereby improving the signal-to-noise ratio ahead of the phase-sensitive detectors. Also, in the same manner that the post-preamp low-pass filter eliminated the image frequencies as a source of error, the I.F. Amplifier attenuates the harmonics, removing them as a potential source of measurement error.

Figure 2-5 shows the I.F. response. With the optional Crystal-Het™ filter, the bandwidth is reduced to 90 Hz. Thus the Signal Mixer accepts synchronous input signal at the reference frequency and transposes it to the I.F. frequency, which is 1.005 MHz. At the output of the Signal Mixer, noise components will be the same number of cycles above or below the I.F. frequency as they are at the signal channel input. However, due to the effects of the Lo Pass Filter and the I.F. Amplifier, noise components above the intermediate frequency will be greatly attenuated. The Lo Pass Filter suppresses image frequency input components and the I.F. Amplifier suppresses harmonics. Together they reduce measurement errors from these sources.

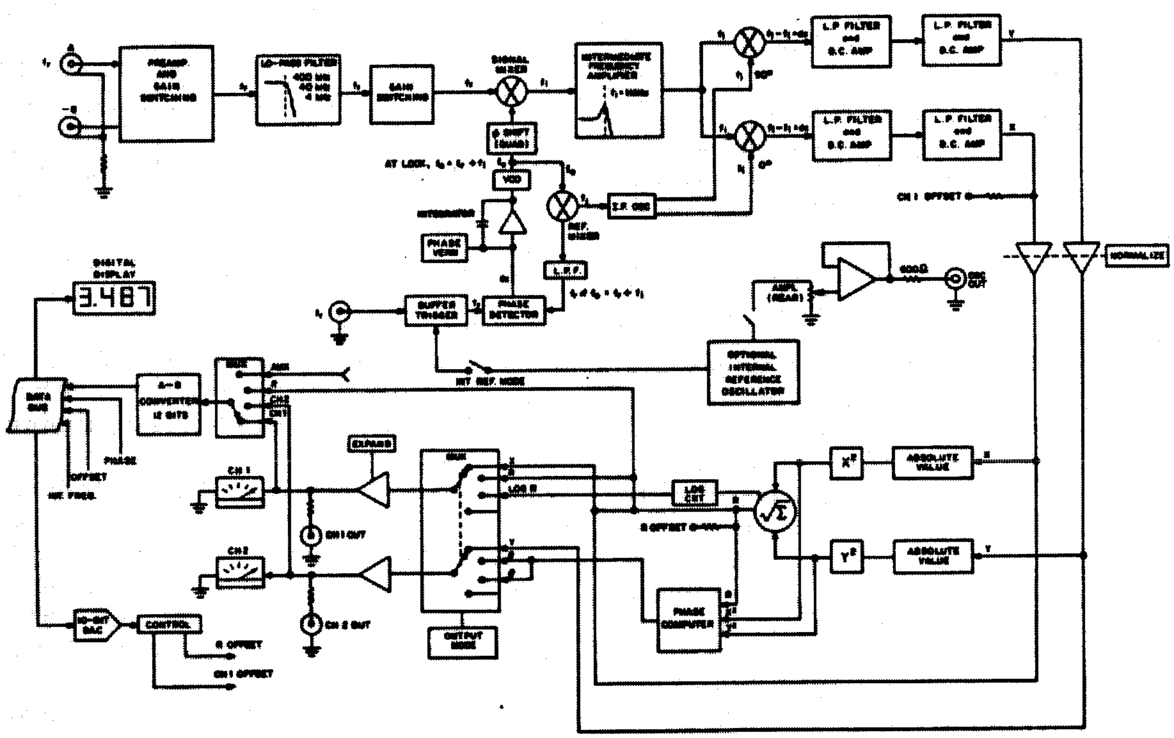


Figure 2-6. BLOCK DIAGRAM

2.3C REFERENCE CHANNEL

The actual reference channel circuitry, even at the block diagram level, is far more complex than depicted in Figure 2-6 and described here. Nevertheless, this description should aid the reader in getting a "feel" for how the reference channel function is achieved.

Referring to Figure 2-6, note that the applied reference signal is buffered and then applied to a Phase Detector. Also applied to the Phase Detector is the output of a Low-Pass Filter, which, in turn, is driven by the Reference Mixer. If the output of the Low-Pass Filter is a signal at f_r, the case when frequency-phase lock is established, there will be no output from the Phase Detector. If the output of the Low-Pass Filter is not at f_r, there will be a net dc output from the Phase Detector. The Phase Detector output is applied to an integrator, which controls a Voltage

Controlled Oscillator (VCO). When there is zero Phase Detector Output, the output of the VCO is constant. If there is a net Phase Detector Output, the output of the VCO will be driven in the direction necessary to restore reference lock.

Note that the VCO output drives the Signal Mixer. It is additionally applied to one input of the Reference Mixer, which has as its other input the output of the I.F. Oscillator. The I.F. Oscillator generates a 1.005 MHz signal at the I.F. Frequency. This signal is mixed with f_o, the output of the VCO, providing sum and difference frequencies. The sum frequency is removed by the Low-Pass Filter. At reference lock, f_o equals $f_r + f_i$. When this is the case, the frequency at the output of the Low-Pass Filter will simply be the difference frequency, f_r. The loop will always operate to establish and maintain this condition. As a result, the Signal Mixer will have applied to it the signal of interest at f_r and the reference signal at $f_r + f_i$. The difference frequency out of the Signal Mixer will be at f_i. This frequency is passed by the I.F. Amplifier and applied to the Demodulators. The Demodulators are driven at f_i by the I.F. Oscillator. The Phase Fine Adjust and Quadrature Step circuits, not shown, operates on the f_o drive to the Signal Mixer.

2.3D OUTPUT CHANNEL

The signal out of the I.F. Amplifier is applied to the Phase Sensitive Detectors. These detectors are driven by a signal at the I.F. frequency produced in the Reference Channel as previously described. The two drives are in quadrature, that is, they are always at 90° with respect to each other. Thus, while one detector demodulates at 0°, the other demodulates at 90°. Coarse Phase and Fine Phase Adjustments work on the drive to the earlier described Signal Mixer. The coarse and fine phase adjustments are used to establish the desired phase relationships at the two Phase Sensitive Detectors. Usually, the phase is set so that the signal input to these detectors will be in phase with the drive to one of them and 90° out of phase with the drive to the other.

Like the previously described mixers, the Phase Sensitive Detectors have sum and difference frequencies at their output. Since the signal and drive inputs to these detectors are at the same frequency, the difference output is at 0 Hz, that is, dc. The magnitude of the dc varies directly with the magnitude of the applied signal frequency and with the cosine of the angle between the signal and drive frequency. Thus, the output will be maximum when the signal is at 0° with respect to the drive, and zero when the signal is at 90° with respect to the drive. The sum component at twice the I.F. frequency will also be present. This component, together with asynchronous noise and interference, is removed by the low-pass filters that follow. There are two filters in each channel. If 6 dB/octave is selected, one filter is "in". If 12 dB/octave is selected, both are "in". The passband is set by the user-selected time constant. The larger the time constant, the greater the noise suppression. Most of the improvement in signal-to-noise ratio achieved by the instrument is provided by these filters. When the phase adjustments have been properly made, the filter output in Ch 1 will be a dc voltage proportional to the rms amplitude of the fundamental frequency component of the synchronous input signal. The filter output of Ch 2 will be zero because of the cosine response of the phase sensitive detector. If the phase relationships at the phase sensitive detectors are other than 0° and 90°, both channels will have non-zero output levels.

The filter outputs are applied to normalizing amplifiers. If the NORMALIZE capability has not been activated, the gain of these amplifiers is fixed so as to provide correct output levels with respect to the selected full-scale sensitivity. On the other hand, if NORMALIZE has been activated, the gain of these amplifiers will be automatically servoed to the value required to give full-scale output ("R" OUT in 5208) for the given input level. Note that the Ch 1 Offset voltage is applied to the Ch 1 Normalizing Amplifier.

These amplifiers are followed by the circuits that develop the various output functions. The magnitude function, R, is developed by taking the square root of the sum of the squares of the individual X and Y output levels. "R" then serves as the input to a Log Converter to generate the LOG R function. A Phase Computer develops a voltage proportional to O, the angle between the signal applied to the "In-Phase" Phase Sensitive Detector and the reference drive to that detector.

As shown in Figure 2-6, these different functions are applied to the Output Mode Multiplexer, which determines which functions will be displayed on the analog meters and provided at the OUTPUT connectors. The Ch 1 and Ch 2 output functions are made available to another Multiplexer, together with "R" and the AUX input line. This multiplexer selects which analog function is to be routed to the input of an A/D Converter. The output of the A/D Converter is placed on the Data Bus. Other inputs to the bus include the Phase setting, the set value of Offset, and the set frequency of the optional Internal Oscillator. The parameter selected with the Display key is routed to the Digital Panel Meter for display. Note that the data bus also drives a ten-bit digital-to-analog converter. This converter receives the digital Offset information and develops from it proportional analog voltages. The Ch 1 Buffer amplifier that follows the Output Mode Multiplexer provides the Expand function. The R Offset voltage is summed with the R input on the appropriate input line of the Output Mode Multiplexer.