SPOKANE DIVISION

HEWLETT · PACKARD

AGENDA

- BASIC PHASE NOISE MEASUREMENT CONCEPTS
- DIRECT SPECTRUM MEASUREMENT
- DEMODULATION TECHNIQUES
- PHASE DEMODULATOR
- RESIDUAL OR ADDED NOISE MEASUREMENTS
- SINGLE SOURCE MEASUREMENTS
- PHASE DETECTOR WITH TWO SOURCES
- REFERENCE SOURCE
- VOLTAGE CONTROLLED SOURCE TUNING REQUIREMENTS
- MEASUREMENT OPTIMIZATION
- MEASUREMENT EXAMPLES

BASIC PHASE NOISE MEASUREMENT CONCEPTS

$$V(t) = V_0[1 + \frac{\epsilon(t)}{V_0}] \sin [2\pi\nu_0 + \phi(t)]$$

$$\parallel$$

$$A(t) \qquad \nu(t) = \nu_0 + \frac{1}{2\pi} \frac{d\phi(t)}{dt}$$

DIRECT SPECTRUM

$S_V(\nu_0 \pm f)$

DEMODULATE, THEN ANALYZE

$S_A(f) \quad S_\phi(f) \quad S_\nu(f) = f^2 S_\phi(f)$

DIRECT SPECTRUM ANALYSIS

IF AM ≪ PM $\qquad \mathcal{L}(f) = \dfrac{S_v(\nu_0 \pm f)}{P_0}$

3582A SPECTRUM ANALYZER

3585A SPECTRUM ANALYZER

3047A SPECTRUM ANALYZER SYSTEM
"DIRECT SPECTRUM" SOFTWARE

8568A SPECTRUM ANALYZER

8566A SPECTRUM ANALYZER

DEMODULATE, THEN ANALYZE

If $\langle \phi^2(t) \rangle \ll 1 \qquad \pounds(f) = \frac{S_\phi(f)}{2}$

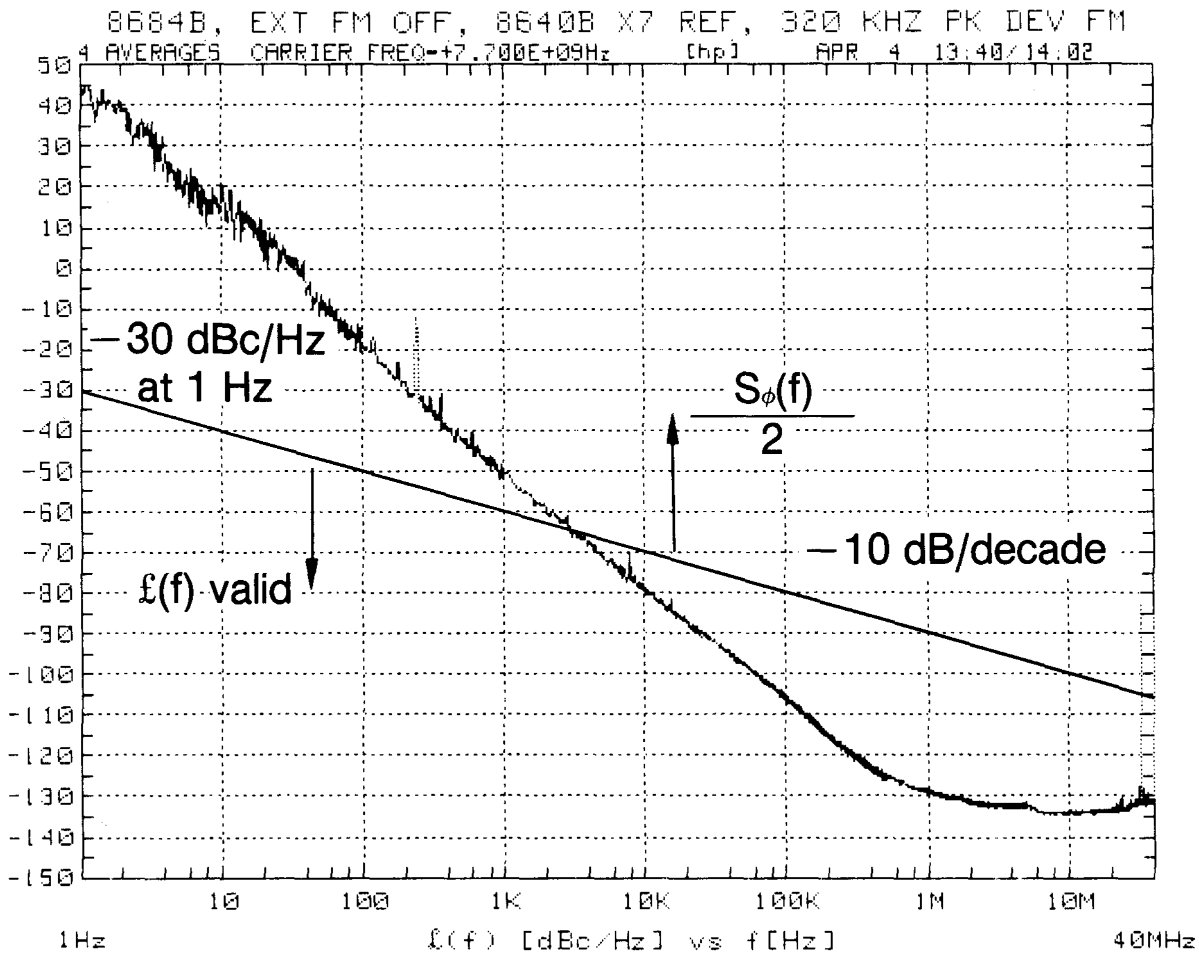
5390A FREQUENCY STABILITY ANALYZER

8901A MODULATION ANALYZER

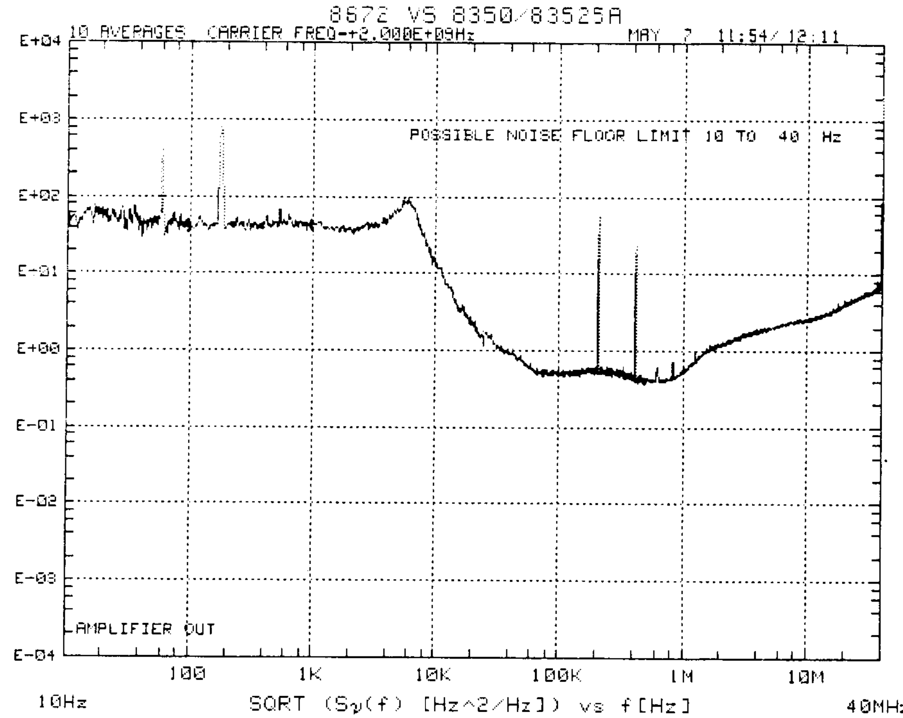
3047A SPECTRUM ANALYZER SYSTEM
"NOISE SIDEBAND" SOFTWARE
"PHASE NOISE" SOFTWARE

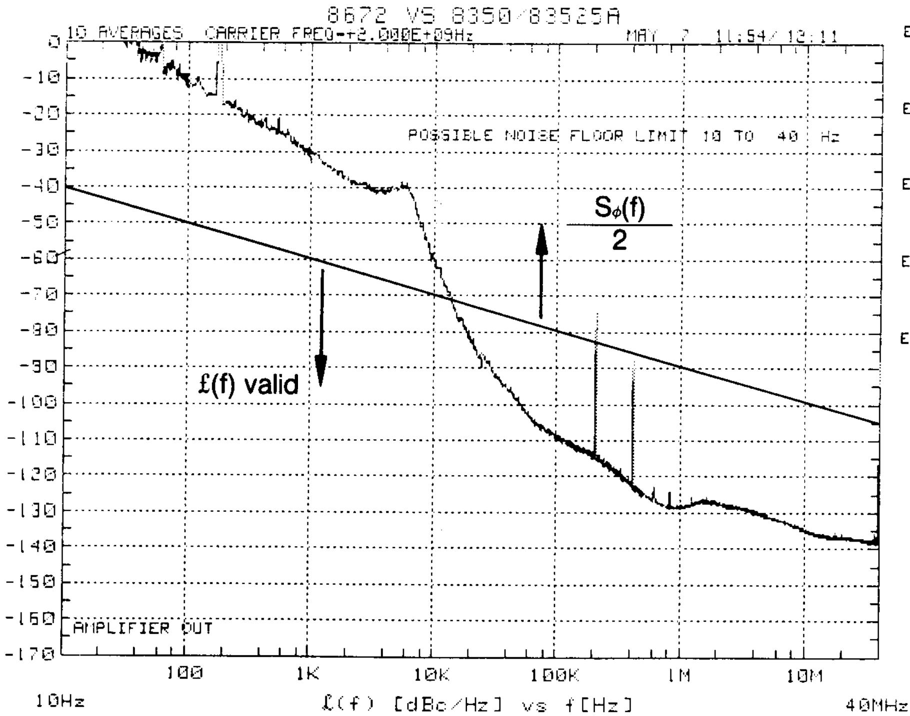
11729A/B LOW NOISE DOWNCONVERTER

REGION OF VALIDITY OF $\mathcal{L}(f) = \frac{S_\phi(f)}{2}$



CONVERSION BETWEEN $S_\phi(f)$ AND $S_\nu(f)$





FOR EXAMPLE 800 Hz rms SPUR
AT 180 Hz IS 4.44 RADIANS rms

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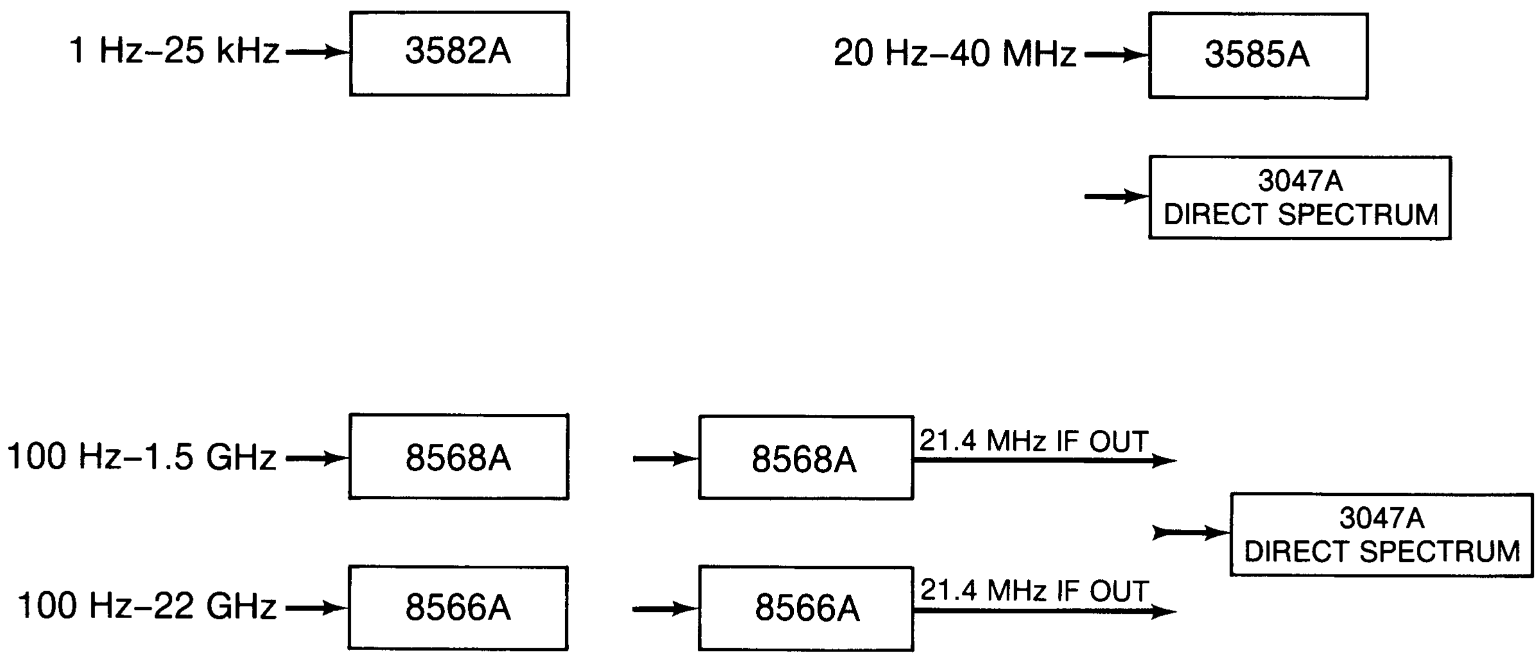
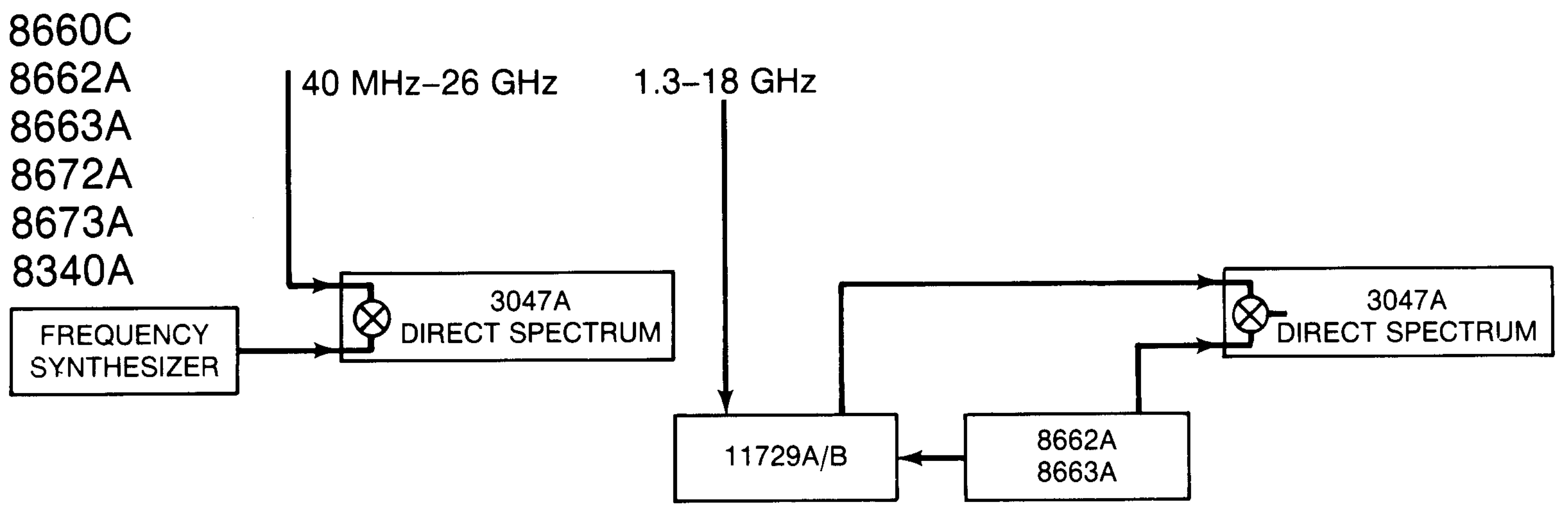
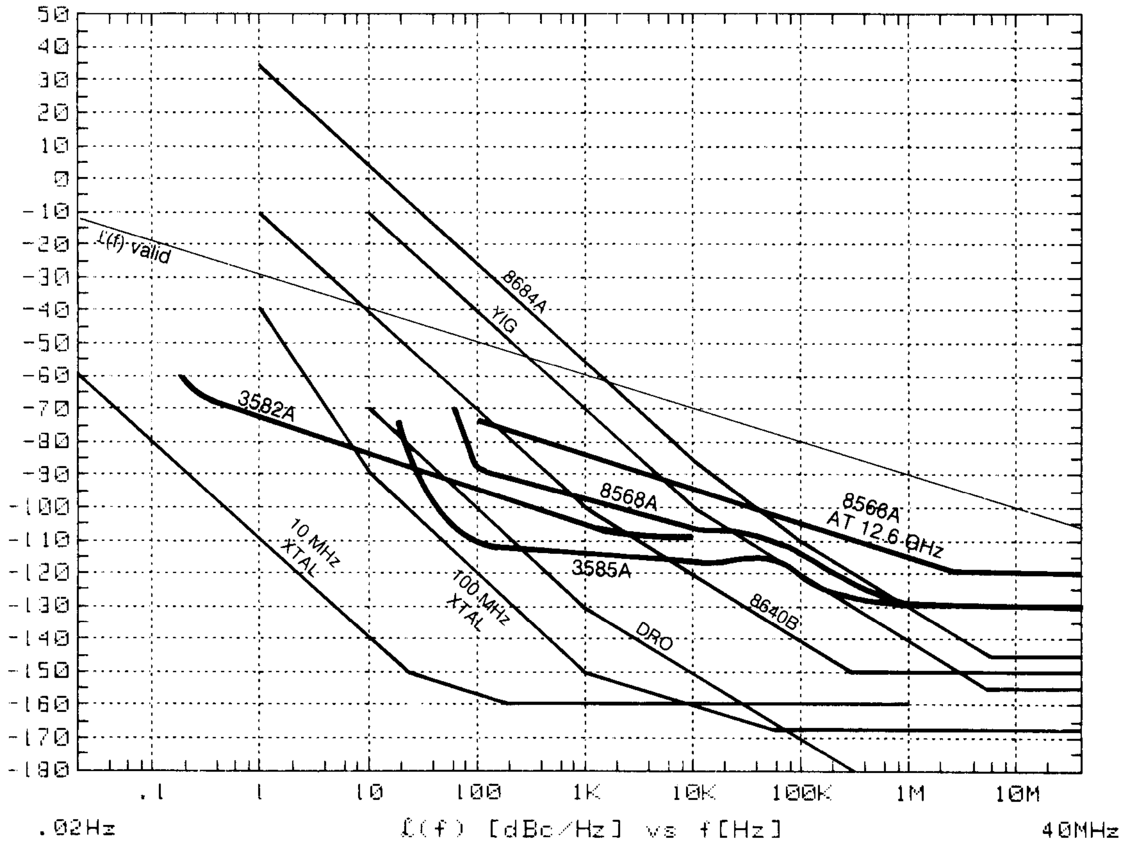
DIRECT SPECTRUM MEASUREMENT CHOICES



DIRECT SPECTRUM MEASUREMENT CHOICES

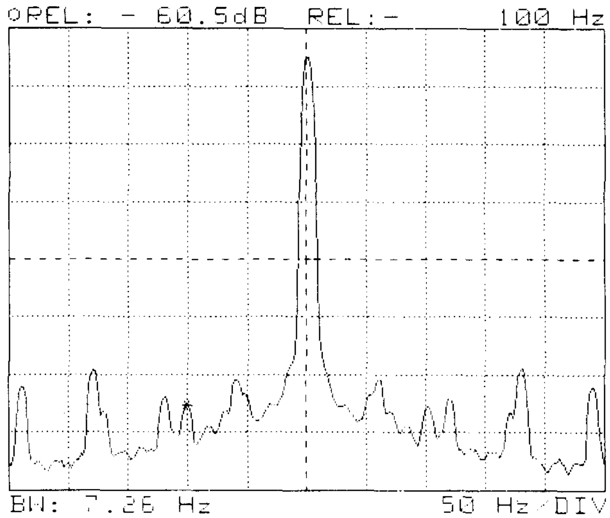


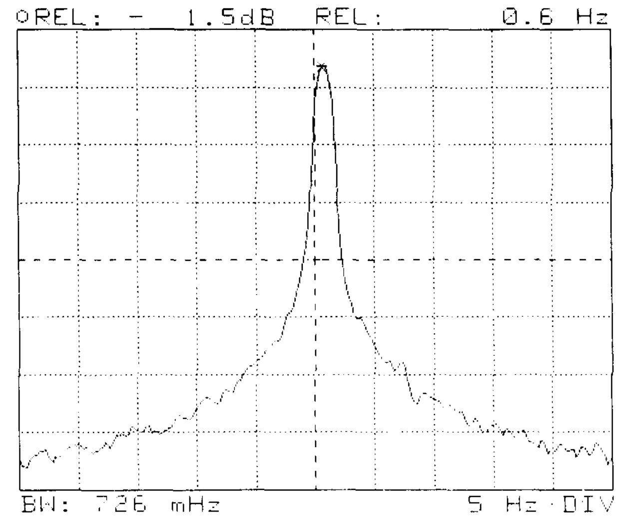
SINGLE SIDEBAND NOISE FLOOR OF SEVERAL SPECTRUM ANALYZERS

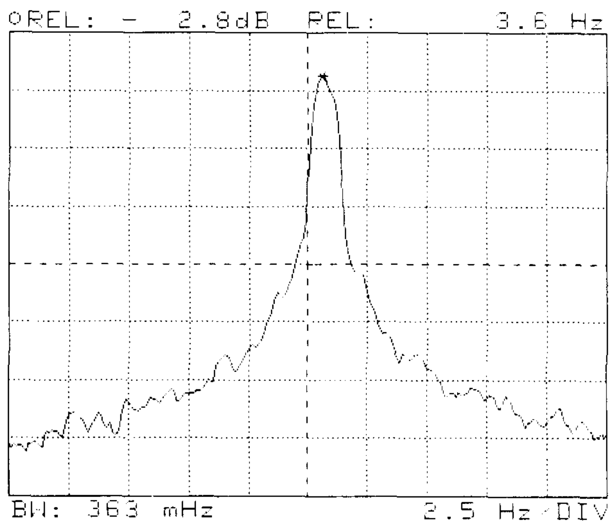


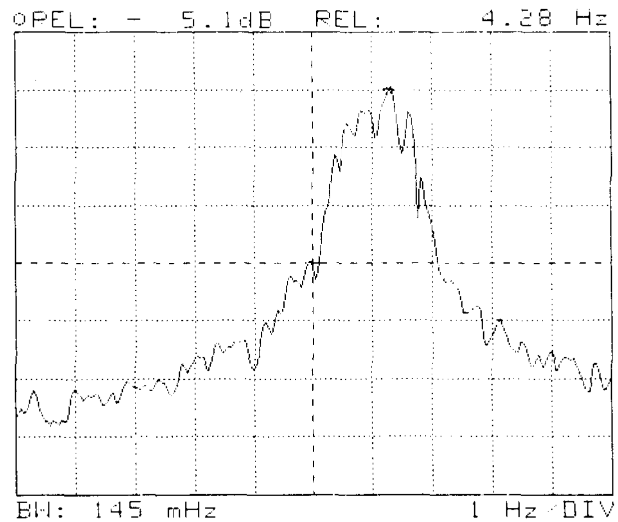
8566A/3047A

DIRECT SPECTRUM AT 12.6 GHz









DIRECT SPECTRUM MEASUREMENT LIMITATIONS

CANNOT SEPARATE AM AND PM NOISE

AM NOISE MUST BE $\ll$ PM NOISE

INADEQUATE DYNAMIC RANGE FOR MANY SOURCES

CANNOT MEASURE CLOSE IN TO A DRIFTING CARRIER

VALUABLE FOR QUALITATIVE QUICK EVALUATION

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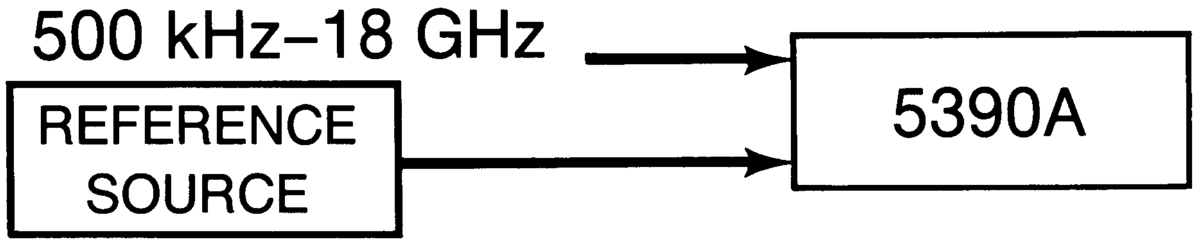
DEMODULATION TECHNIQUES RELATED TO SPECIFIC INSTRUMENTS OR SYSTEMS

5390A FREQUENCY STABILITY ANALYZER

8901A MODULATION ANALYZER

3047A SPECTRUM ANALYZER SYSTEM
"NOISE SIDEBAND" SOFTWARE

5390A FREQUENCY STABILITY ANALYZER

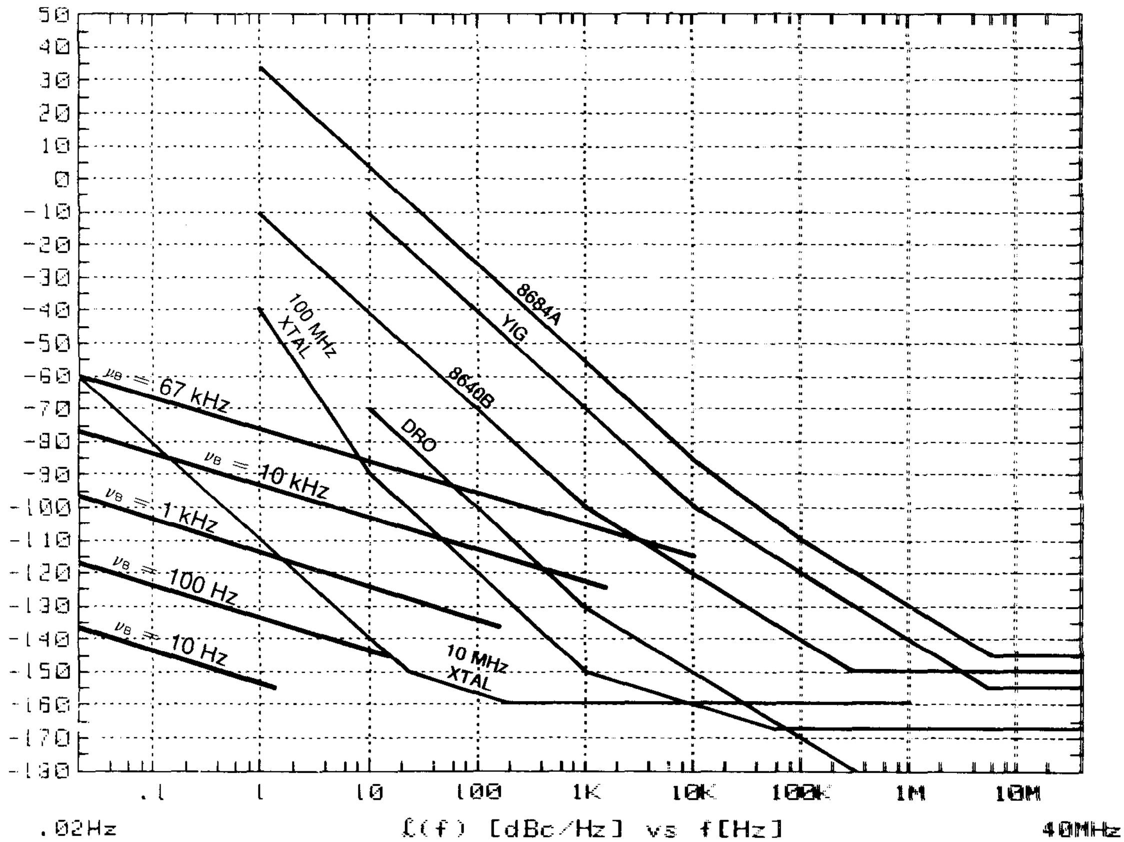


3325A, 3335A
8660C
8662A, 8663A
8672A, 8673A
8430A
11729A/8662/3A

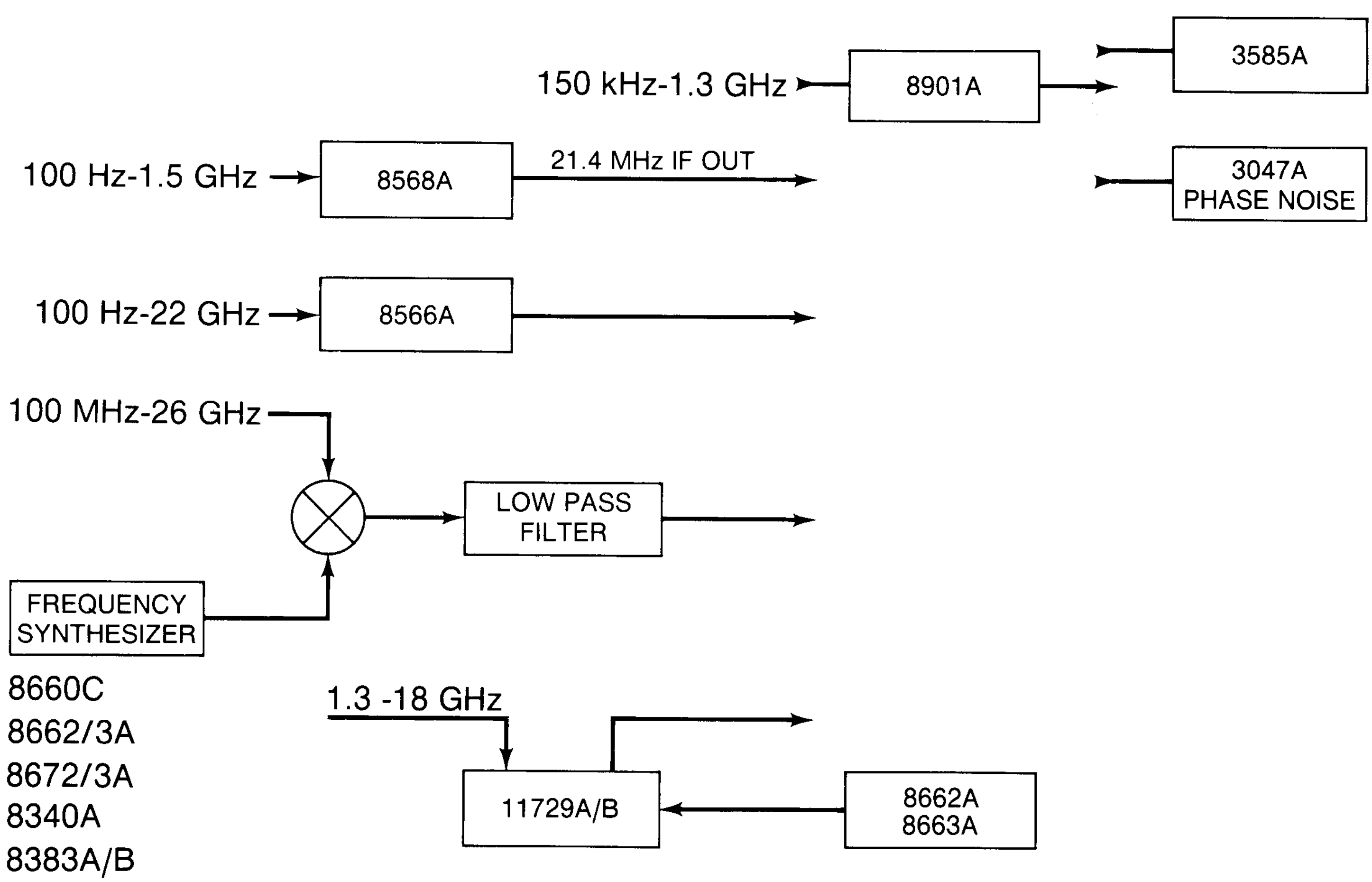
Offset from source under test by 10 Hz $\leq \nu_B \leq$ 67 kHz.
Source drift $\ll \nu_B$.
Noise must fall rapidly with increasing f.

5390A FREQUENCY STABILITY ANALYZER

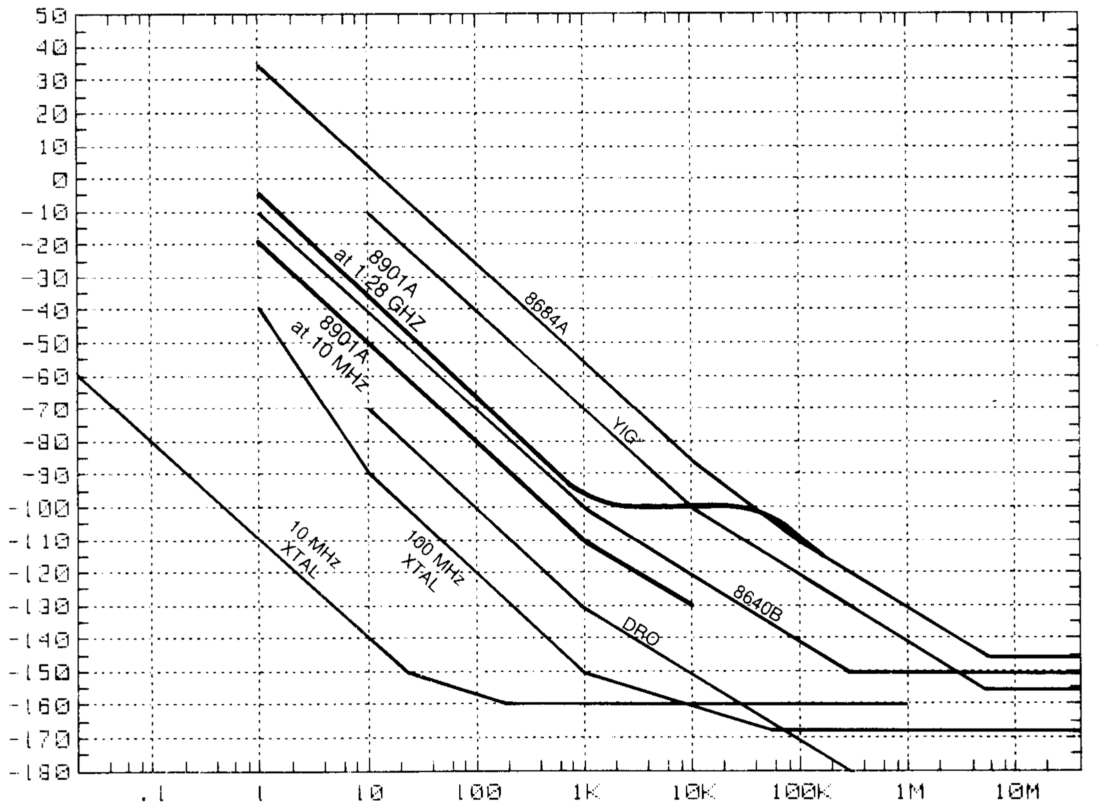
THEORETICAL SENSITIVITY



8901A MODULATION ANALYZER



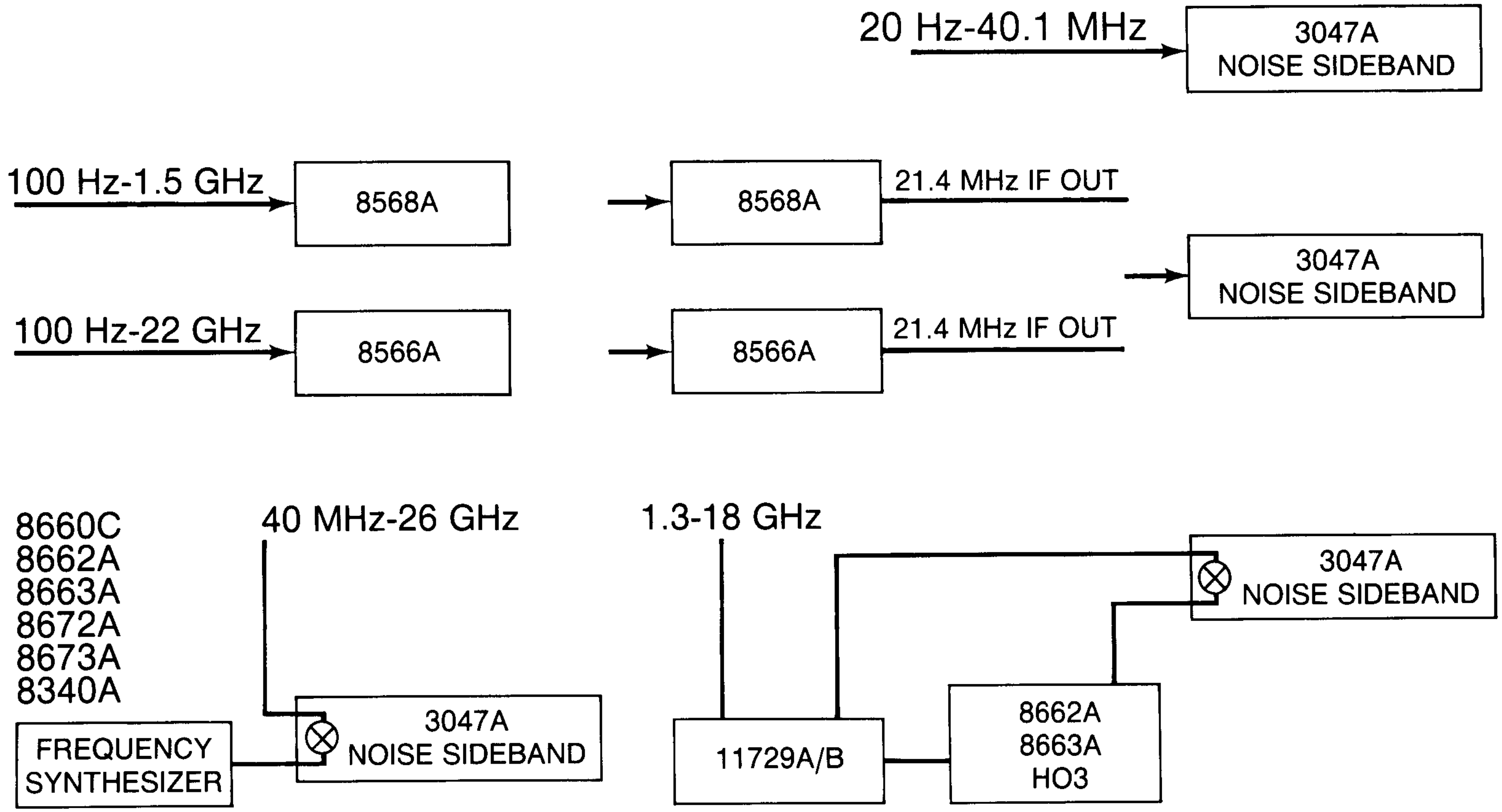
8901A PHASE NOISE



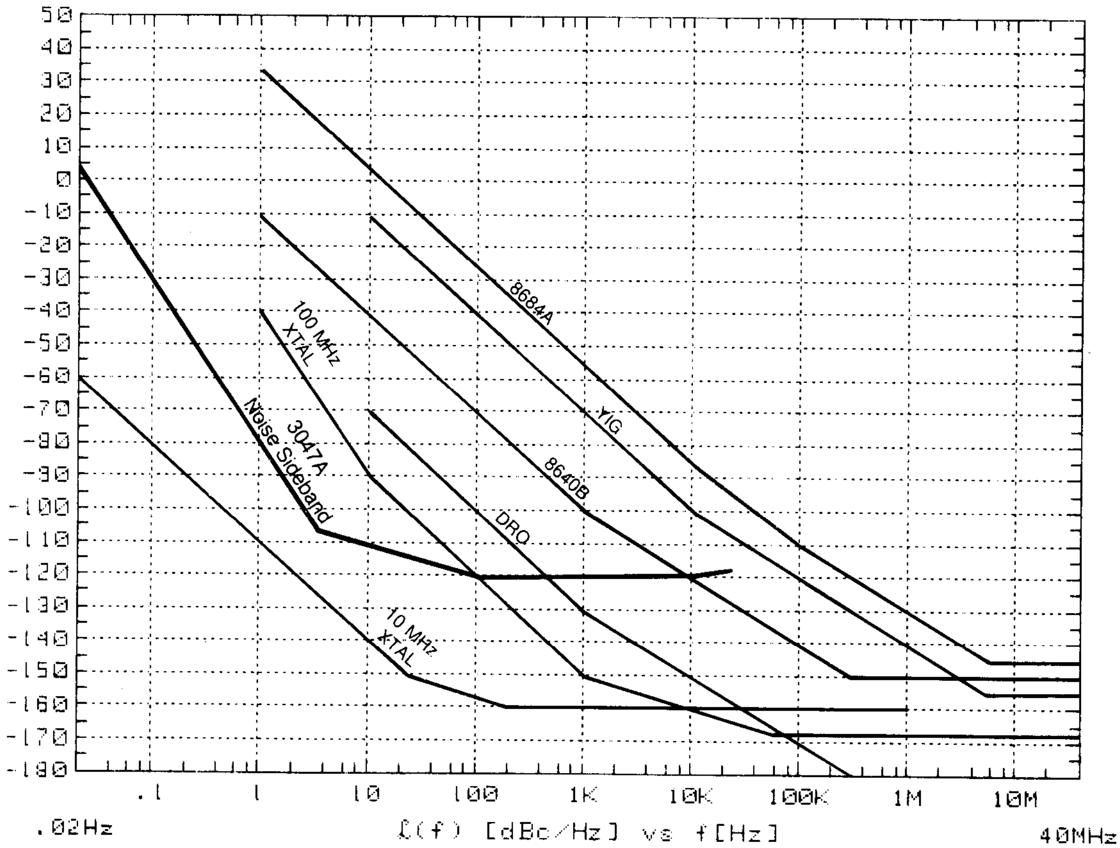
£(f) [dBc/Hz] vs f[Hz]

3047A NOISE SIDEBAND SOFTWARE

SOURCE FREQUENCY DRIFT ≤ 150 Hz



3047A NOISE SIDEBAND
MEASURED PM NOISE FLOOR



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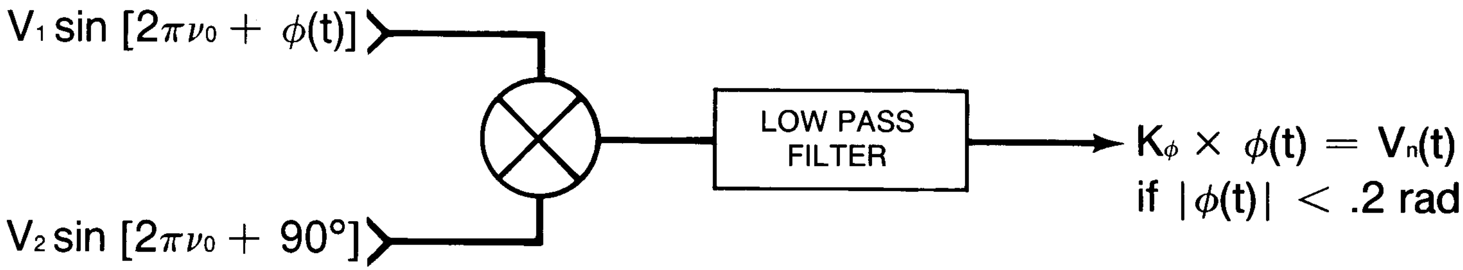
DOUBLY BALANCED MIXER AS PHASE DETECTOR

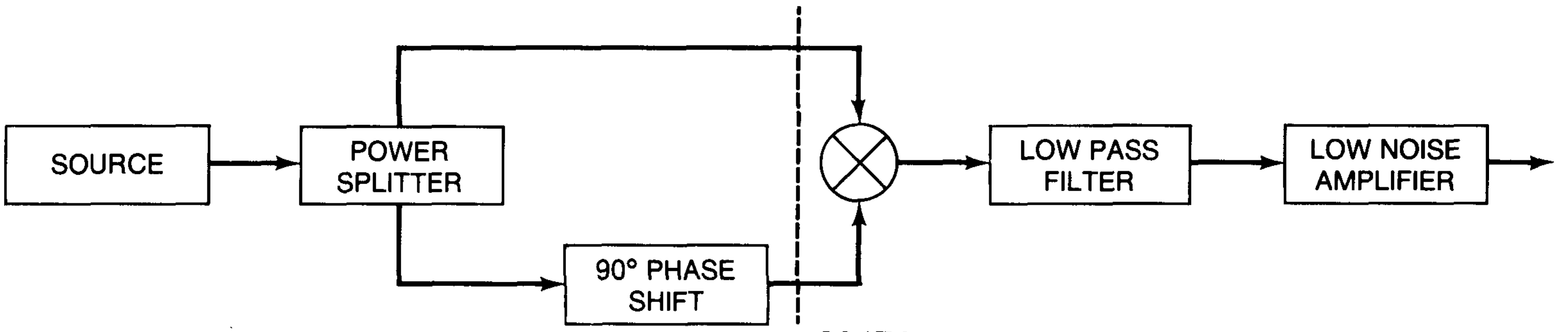


$$S_\phi(f) = \frac{S_n(f)}{K^2_\phi}$$

$$S_\nu(f) = f^2 S_\phi(f) = \frac{f^2 S_n(f)}{K^2_\phi}$$

$$\pounds(f) = \frac{S_\phi(f)}{2} = \frac{S_n(f)}{2K^2_\phi} \quad \text{because } |\phi(t)| < .2 \text{ rad}$$

MEASUREMENT OF PHASE DETECTOR SYSTEM NOISE FLOOR

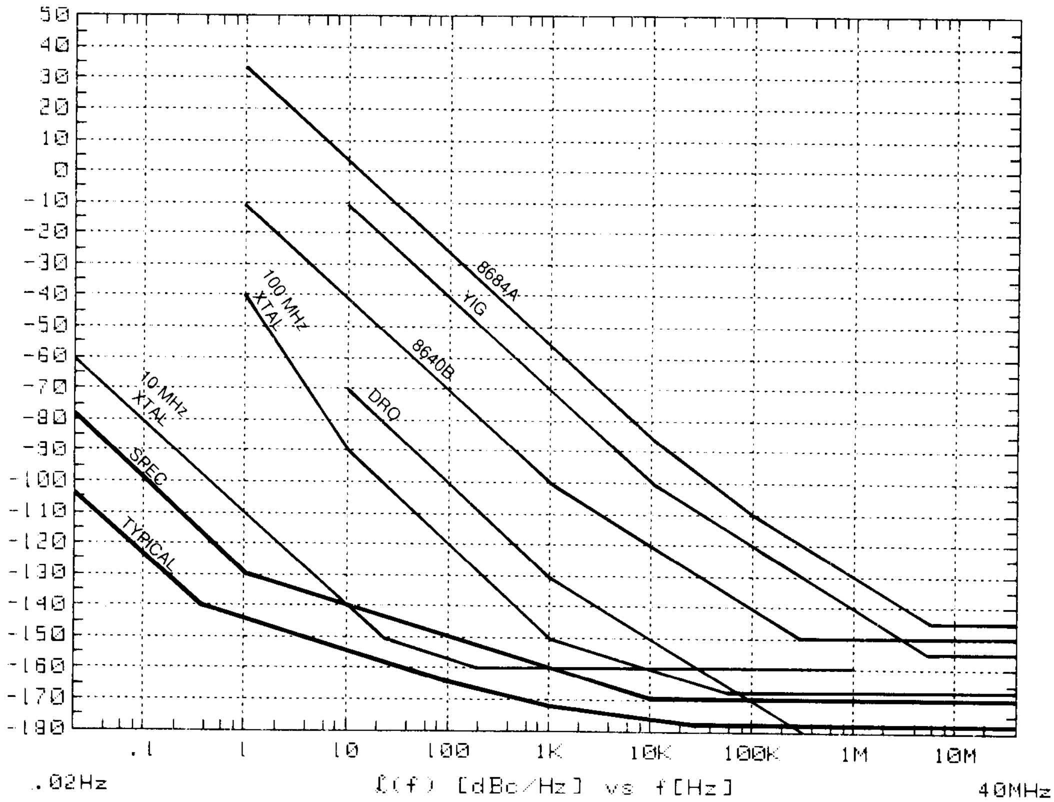


CONCERNS:

- AM NOISE OF SOURCE
- DECORRELATION OF SOURCE BROADBAND PM NOISE FLOOR BY DELAY IN ONE PATH
- TYPICAL AM REJECTION ≈ 30 dB TO 1.6 GHz
  ≈ 15 dB AT HIGHER FREQUENCIES

3047A PHASE NOISE MEASUREMENT NOISE FLOOR

5 MHz-1.6 GHz
+15 dBm SOURCES



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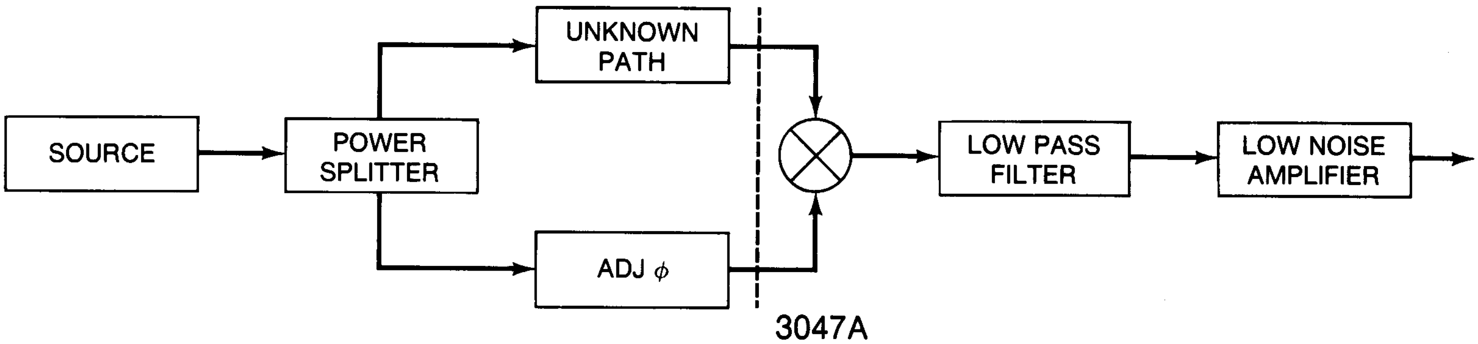
MEASUREMENT OF A SINGLE FREQUENCY SIGNAL PROCESSOR

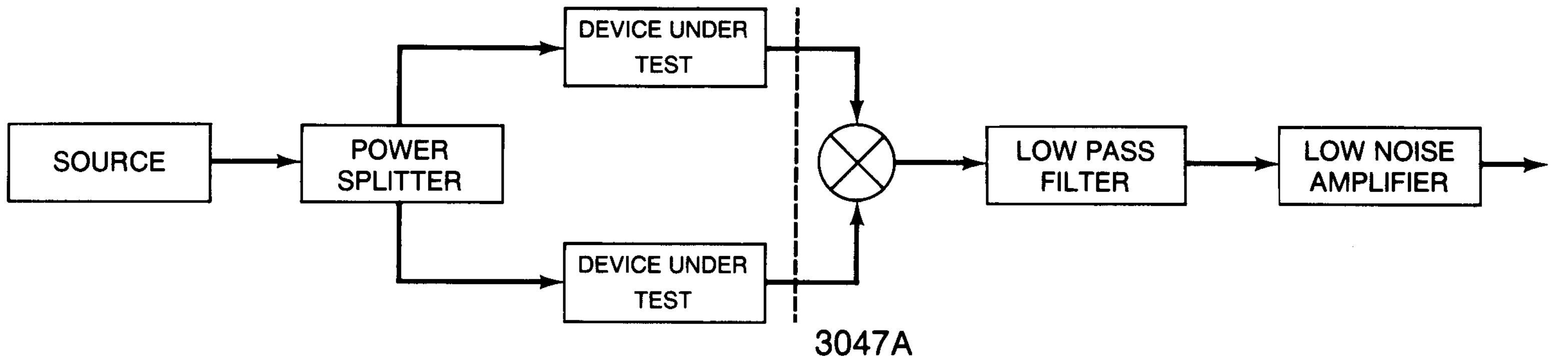


CONCERNS:

FILTERING EFFECT OF UNKNOWN PATH

TIME DELAY IN UNKNOWN PATH

MEASUREMENT OF A FREQUENCY MULTIPLIER, DIVIDER OR TRANSLATOR



RMS sum of noise of both devices is measured.

Measurement sets upper limit on noise of each device.

At each offset frequency one device is at least 3 dB better.

Three source comparison software will sort out the noise of 3 comparable devices.

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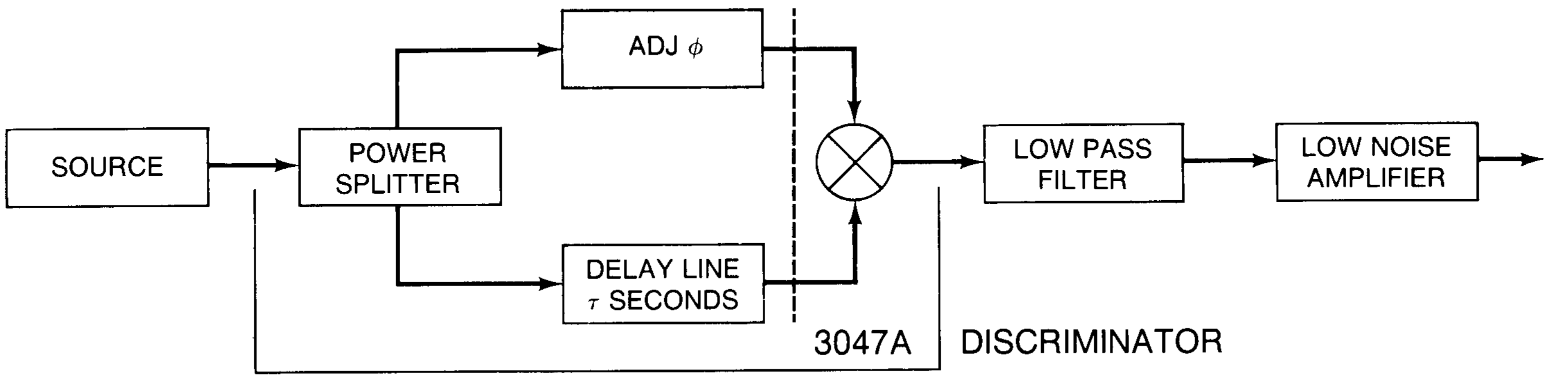
MEASUREMENT OF THE NOISE OF A SINGLE SOURCE



A delay line bridge or cavity resonator may be used.
Since delay is a linear phase shift with frequency,
the phase detector output represents frequency fluctuations.

$$K_D\left[\frac{V}{Hz}\right] = K_\phi \times 2\pi\tau \frac{\sin \pi f \tau}{\pi f \tau}$$

$$K_D\left[\frac{V}{Hz}\right] = K_\phi \times 2\pi\tau \ \text{for} \ f \leq \frac{1}{2\pi\tau}$$

PHASE NOISE CALIBRATION OF A DISCRIMINATOR

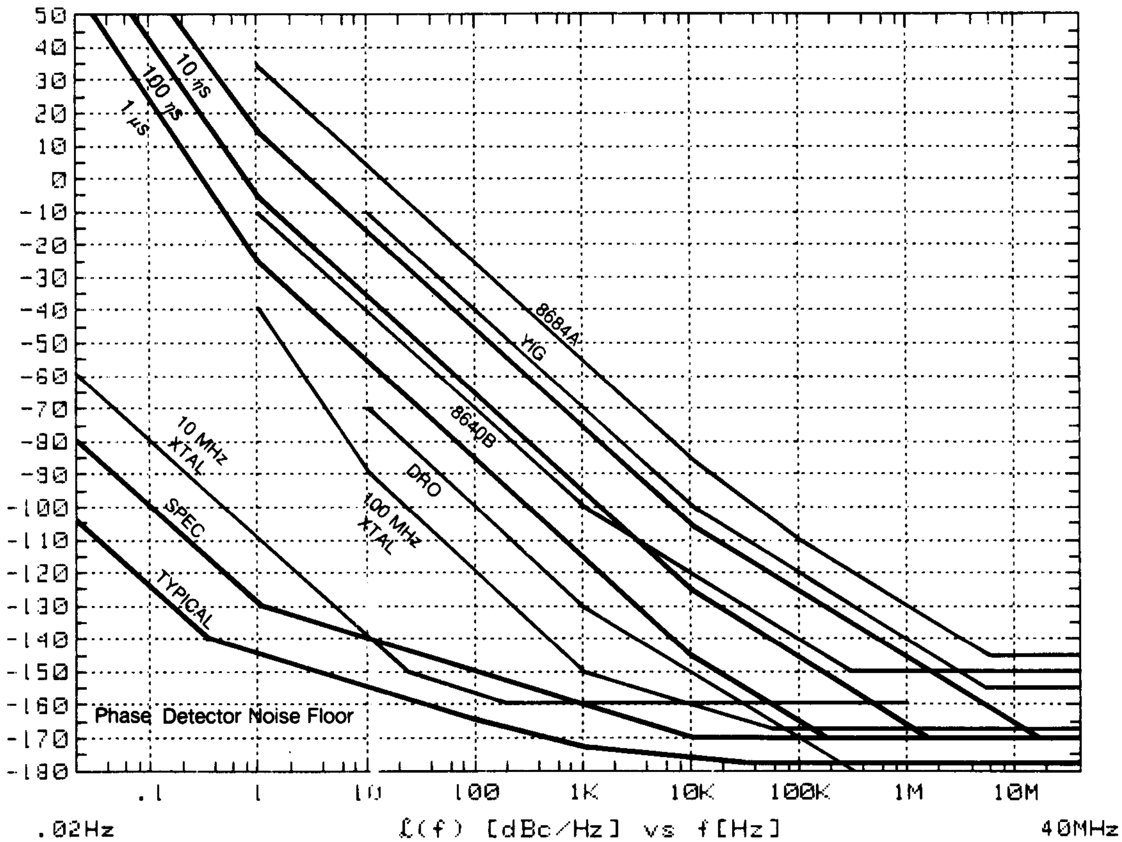
$$S_\nu(f) = \frac{S_n(f)}{K_d^2} \qquad S_\phi(f) = \frac{S_n(f)}{f^2 K_d^2}$$

If $\langle \phi^2(t) \rangle$ (of source) $\ll 1$ then $\pounds(f) = \dfrac{S_n(f)}{2f^2 K_d^2}$

Approximate sensitivity is phase detector system sensitivity at $f = \dfrac{1}{2\pi\tau}$ and tipped up by 20 dB/decade for $f < \dfrac{1}{2\pi\tau}$

Calibration valid for $f \leq \dfrac{1}{2\pi\tau}$ and
to $f = \dfrac{1}{2\tau}$ with correction for $\dfrac{\sin \pi f \tau}{\pi f \tau}$

DELAY LINE DISCRIMINATOR APPROXIMATE SENSITIVITY



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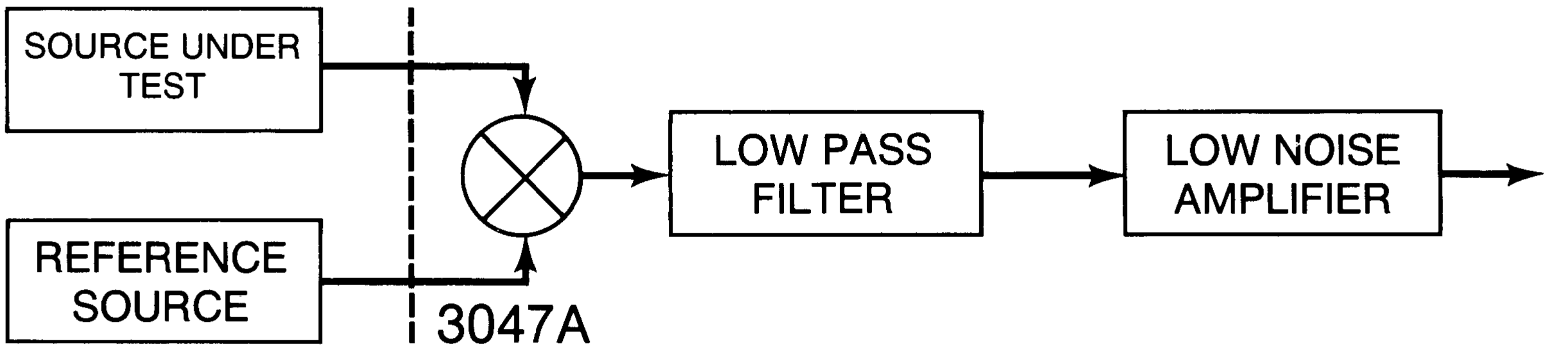
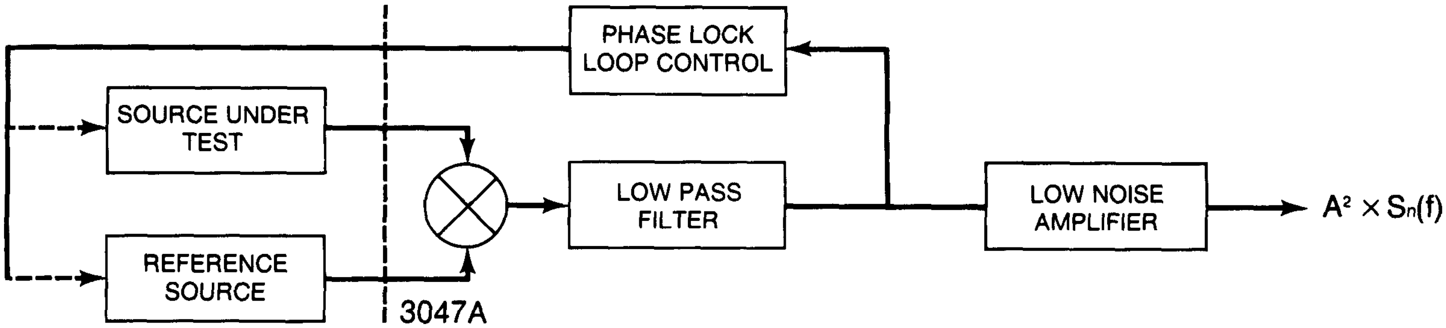
TWO SOURCE COMPARISON FOR VERY STABLE SOURCES



IMPRACTICAL BECAUSE OF REQUIRED PHASE STABILITY TO MAINTAIN QUADRATURE FOR THE DURATION OF THE MEASUREMENT.

RANGE OF f LIMITED ONLY BY ANALYZER AND FILTER

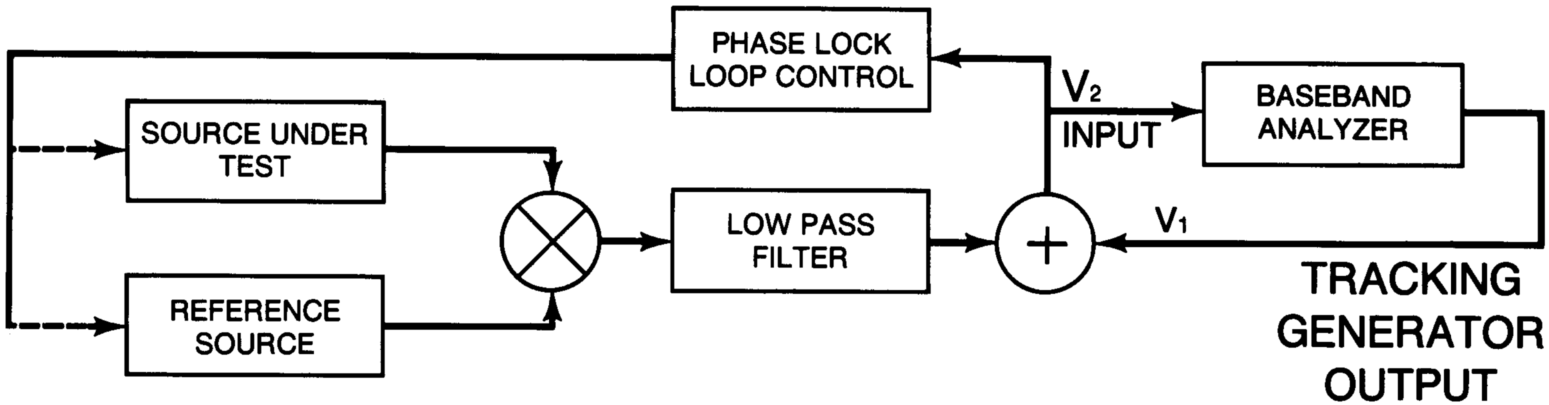
USE OF A PHASE LOCK LOOP TO MAINTAIN PHASE QUADRATURE



$$S_\phi(f) = \frac{S_n(f)}{K_\phi^2} \times \left|1 + \text{Forward Gain of phase-lock-loop}\right|^2$$

$$S_\phi(f) = \frac{S_n(f)}{K_\phi^2} \text{ for } f \gg \text{Phase-lock-loop bandwidth}$$

MEASUREMENT OF EFFECT OF PHASE-LOCK-LOOP



$$\frac{|V_2|}{|V_1|} = \frac{1}{|1 + \text{Forward Gain of Phase-lock-loop}|}$$

This ratio is calculated from known constants and then verified by the above technique.

Full range of f available.

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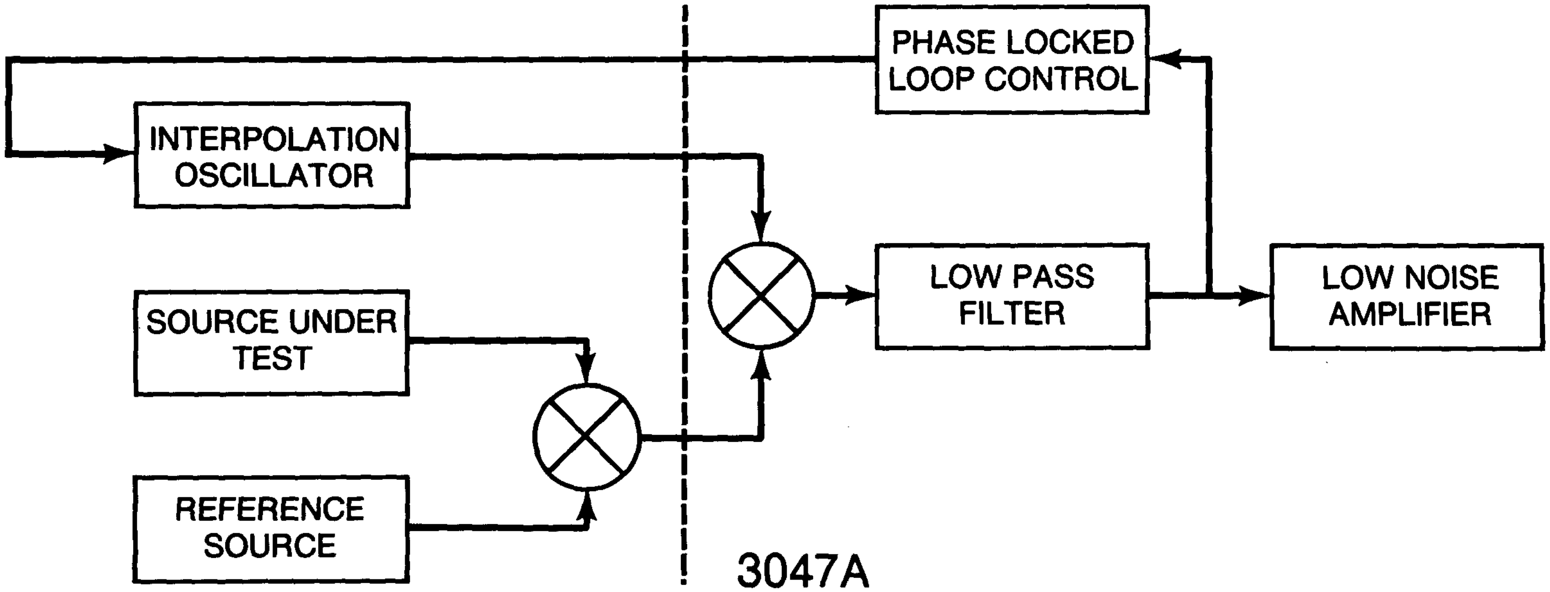
REFERENCE SOURCE CONSIDERATIONS

- IDEALLY PHASE NOISE 10 dB BELOW SOURCE UNDER TEST FOR ALL f OF INTEREST
- PRACTICAL ALTERNATIVES:
  - Different Reference Sources for different f.
  - Reference Source Comparable to Source under test
  - Three comparable sources and three source comparison software
- EITHER SOURCE UNDER TEST OR REFERENCE SOURCE MUST BE TUNABLE WITH ONE EXCEPTION, PHASE LOCKED INTERPOLATION OSCILLATOR

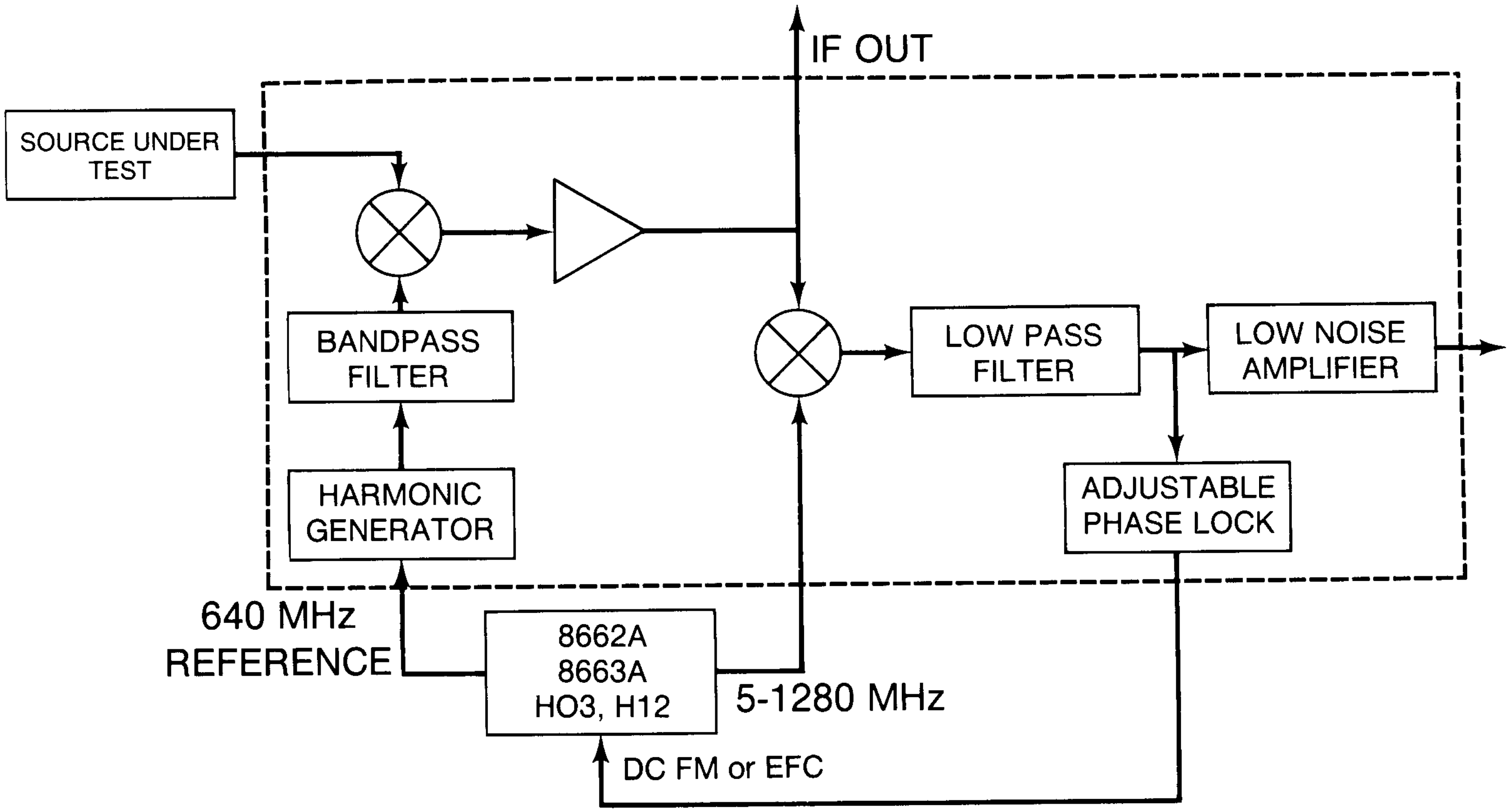
PHASE LOCKED INTERPOLATION OSCILLATOR



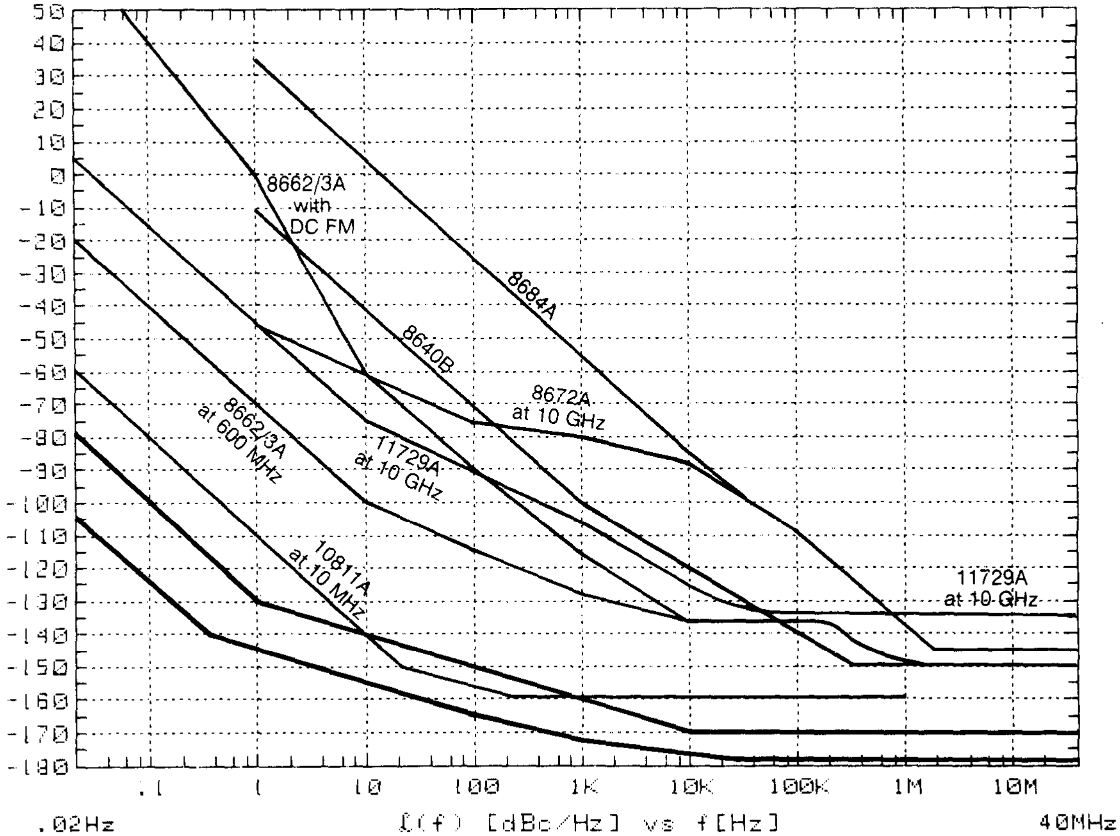
Useful for microwave frequencies and above since only a single diode mixer is required

The 11729A/B is a specific implementation of this approach.

11729A/B LOW NOISE DOWNCONVERTER



PHASE NOISE OF SOME REFERENCE SOURCES



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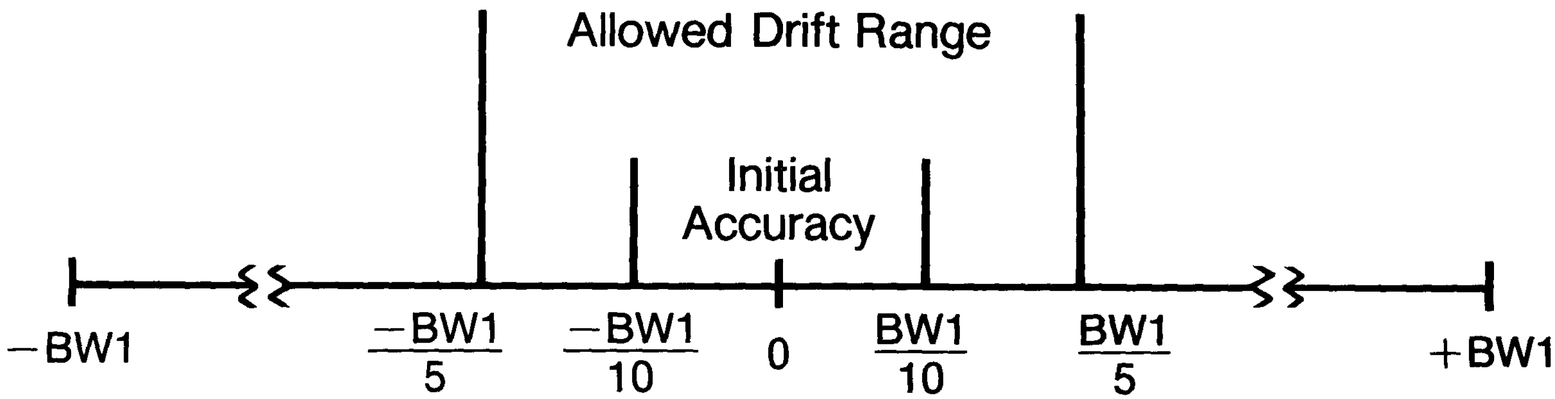
VOLTAGE CONTROLLED SOURCE TUNING REQUIREMENTS (I)

PEAK TUNING RANGE = BW1 $\approx V_{range} \times VCO_{slope}$

PHASE LOCK LOOP FREQUENCY RESPONSE TAILORING AVAILABLE FOR .1 Hz $\leq$ BW1 $\leq$ 200 MHz

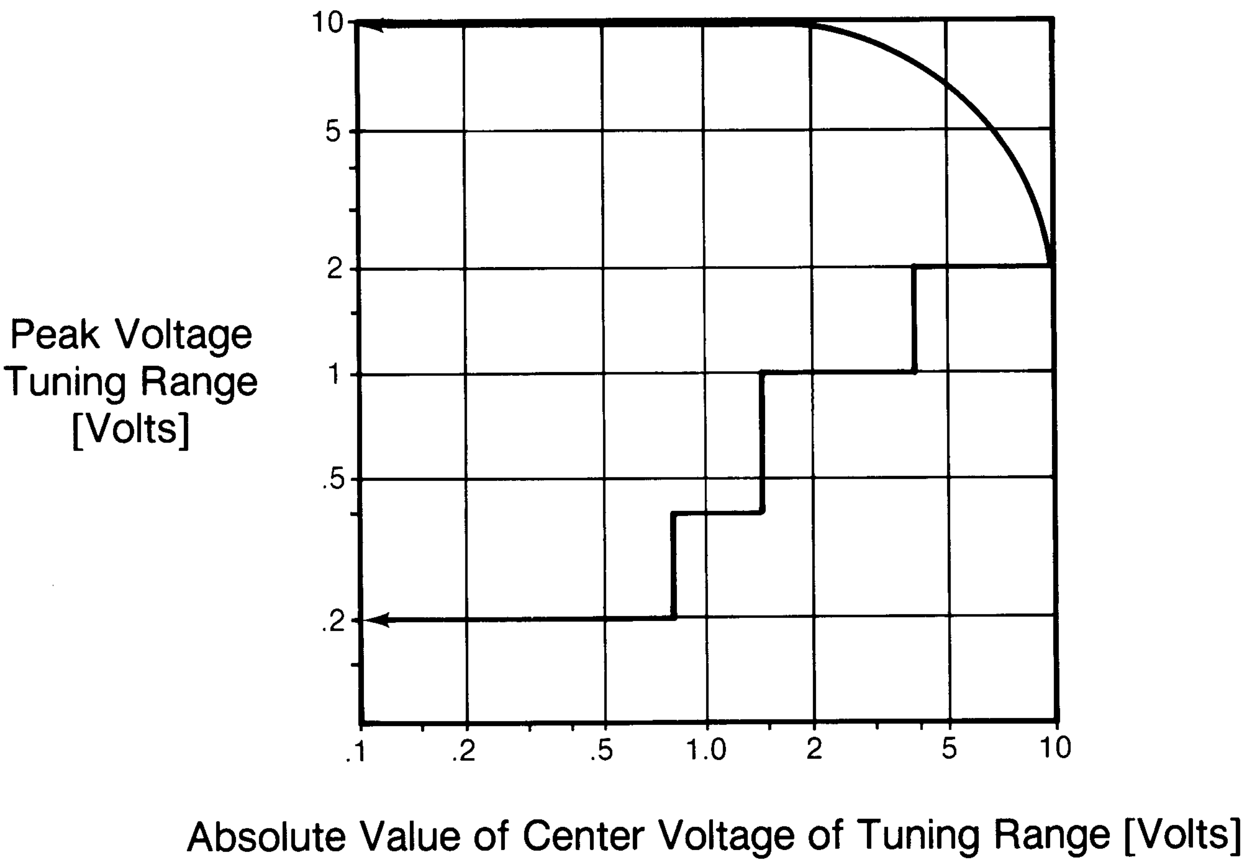
INITIAL TUNING INACCURACY $\leq$ BW1/10

DRIFT DURING MEASUREMENT $\pm$ BW1/5 AROUND ZERO BEAT



Relative Frequency of reference and test sources

ALLOWED VOLTAGE TUNING RANGE vs. CENTER VOLTAGE OF TUNING RANGE



VOLTAGE CONTROLLED SOURCE TUNING REQUIREMENTS (II)

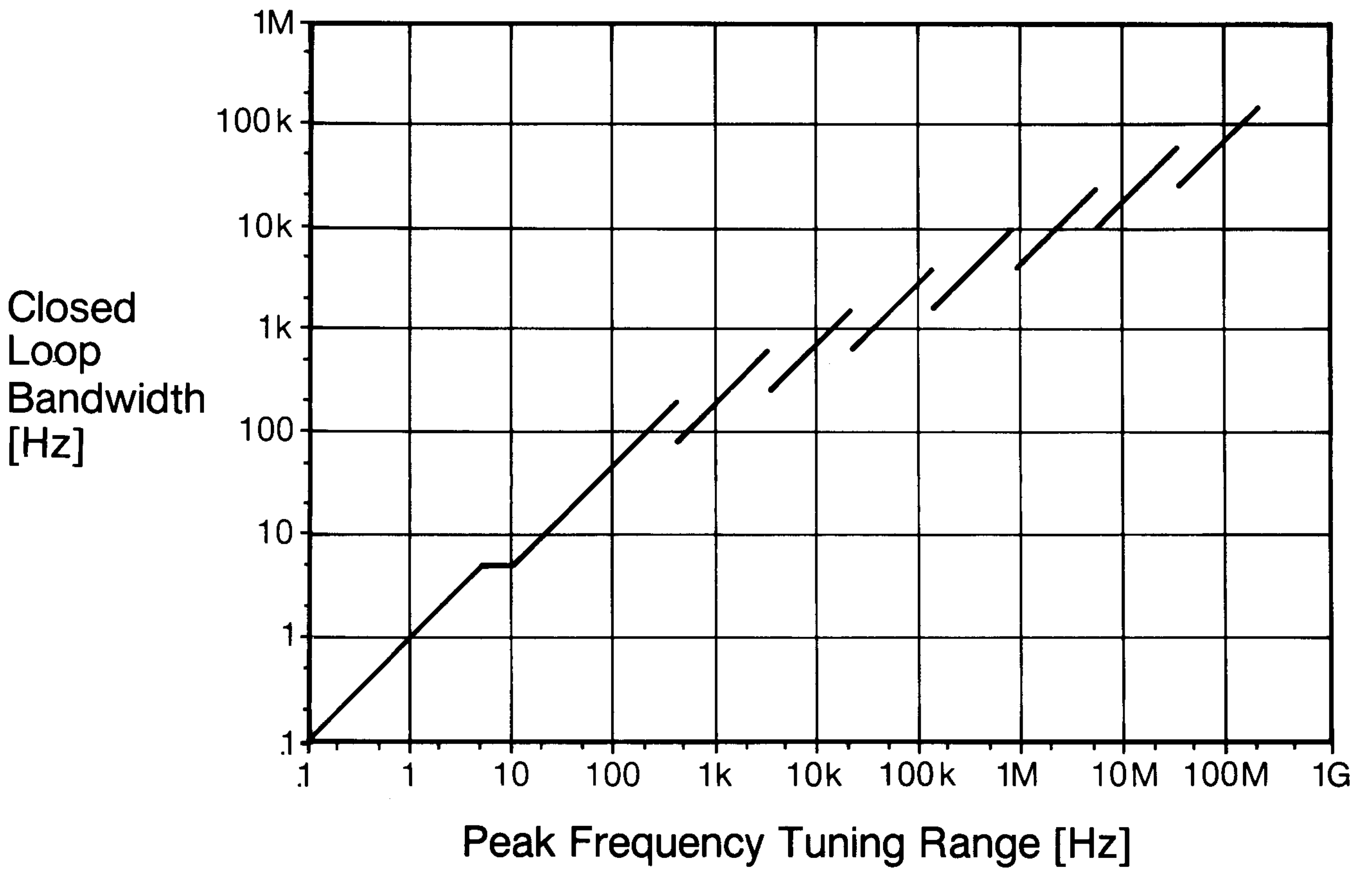
- FOR .1 Hz $\leq$ BW1 $\leq$ 200 MHz
  .1 Hz $\leq$ BW3 $\leq$ 160 kHz

  WHERE BW3 = CLOSED LOOP BANDWIDTH OF PHASE-LOCKED-LOOP

- FOR A STABLE PHASE-LOCKED-LOOP:
  VOLTAGE CONTROLLED SOURCE TUNING PORT BANDWIDTH $>$ BW3

- SOURCE ISOLATION SUCH THAT
  INJECTION LOCKING BANDWIDTH $\ll$ BW3

CLOSED LOOP BANDWIDTH (BW3)
vs. PEAK FREQUENCY TUNING RANGE (BW1)

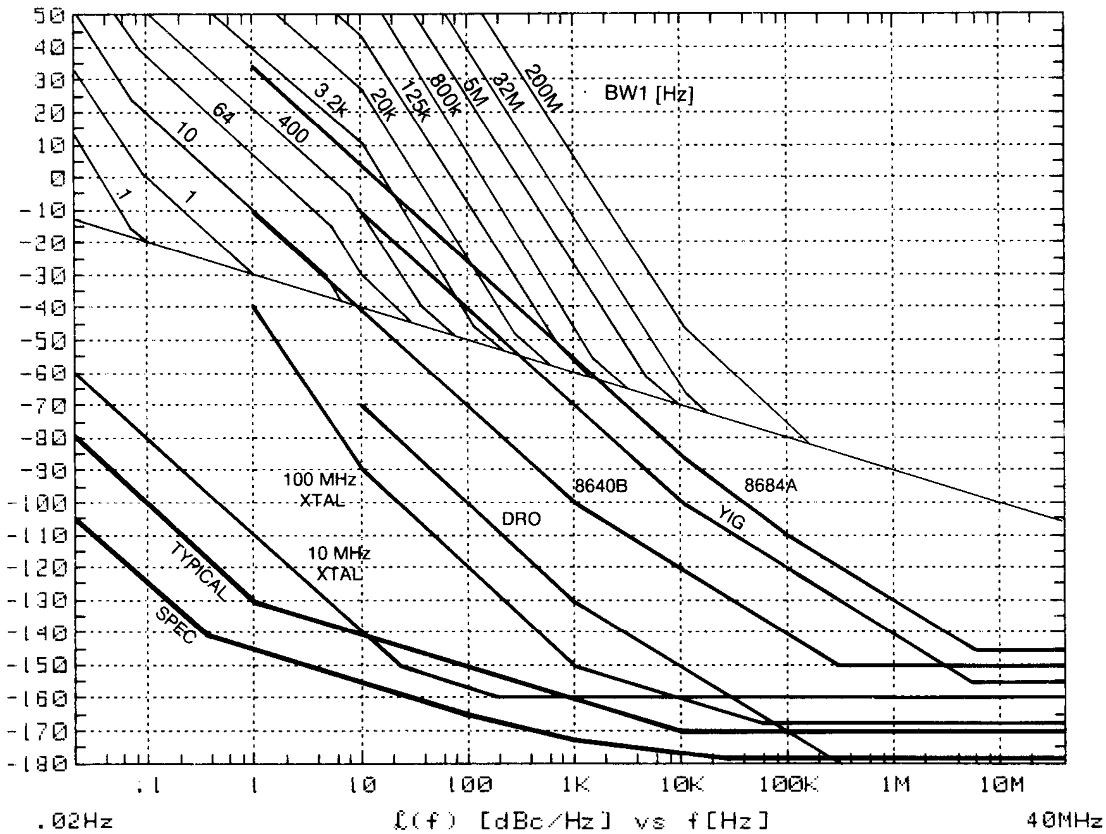


VOLTAGE CONTROLLED SOURCE TUNING REQUIREMENTS (III)

- FOR ALMOST ALL SOURCES WITHOUT A HIGH PHASE NOISE PEDESTAL, SATISFYING THE PRECEEDING REQUIREMENTS WILL RESULT IN A STABLE PHASE-LOCK-LOOP.

- THE ALLOWABLE PHASE NOISE PEDESTAL IS PRIMARILY A FUNCTION OF THE PEAK TUNING RANGE, BW1, AND THEREFORE MAY SET THE SOURCE TUNING RANGE REQUIREMENTS.

PEAK FREQUENCY TUNING RANGE (BW1) REQUIRED TO PHASE LOCK



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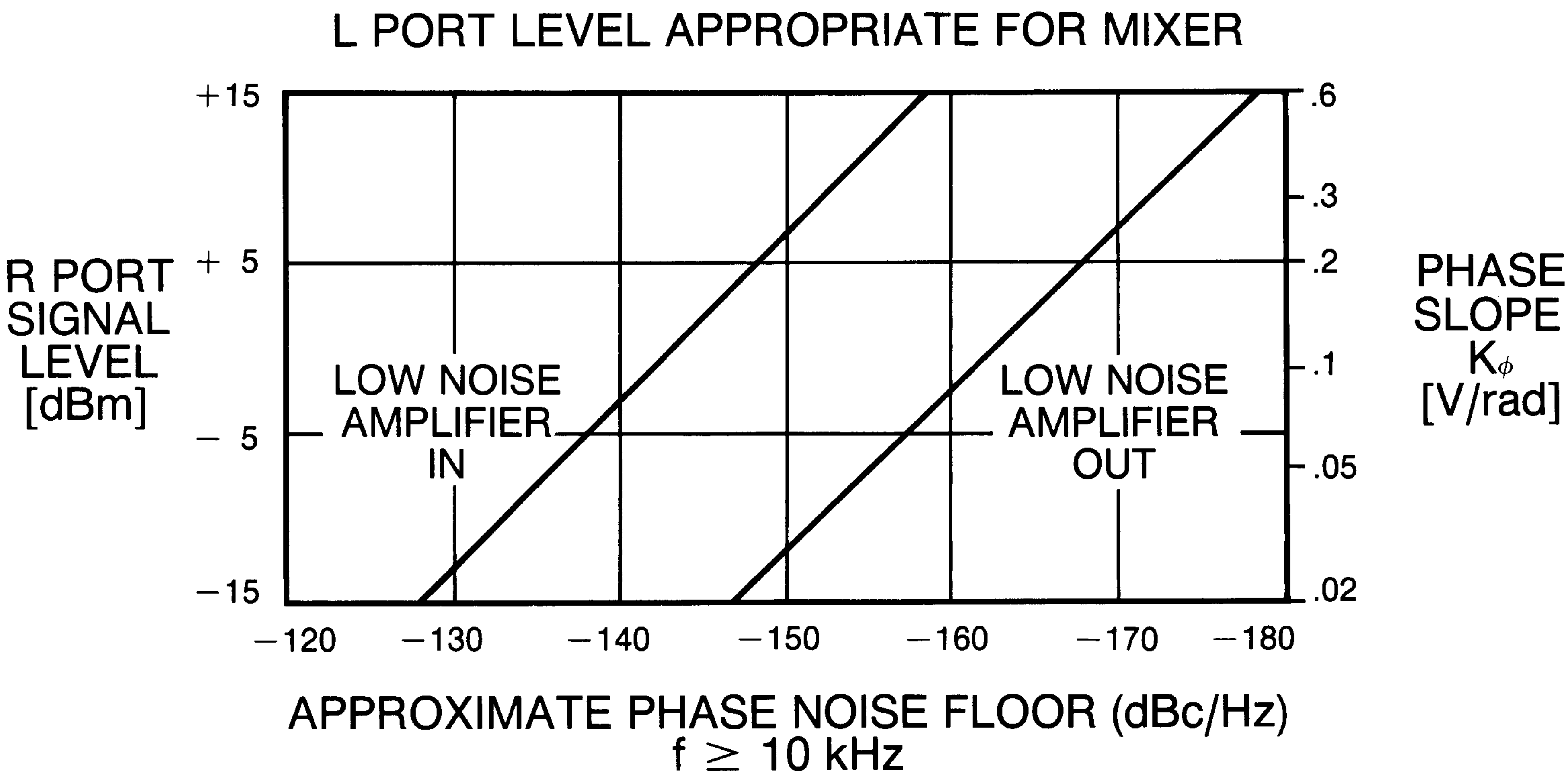
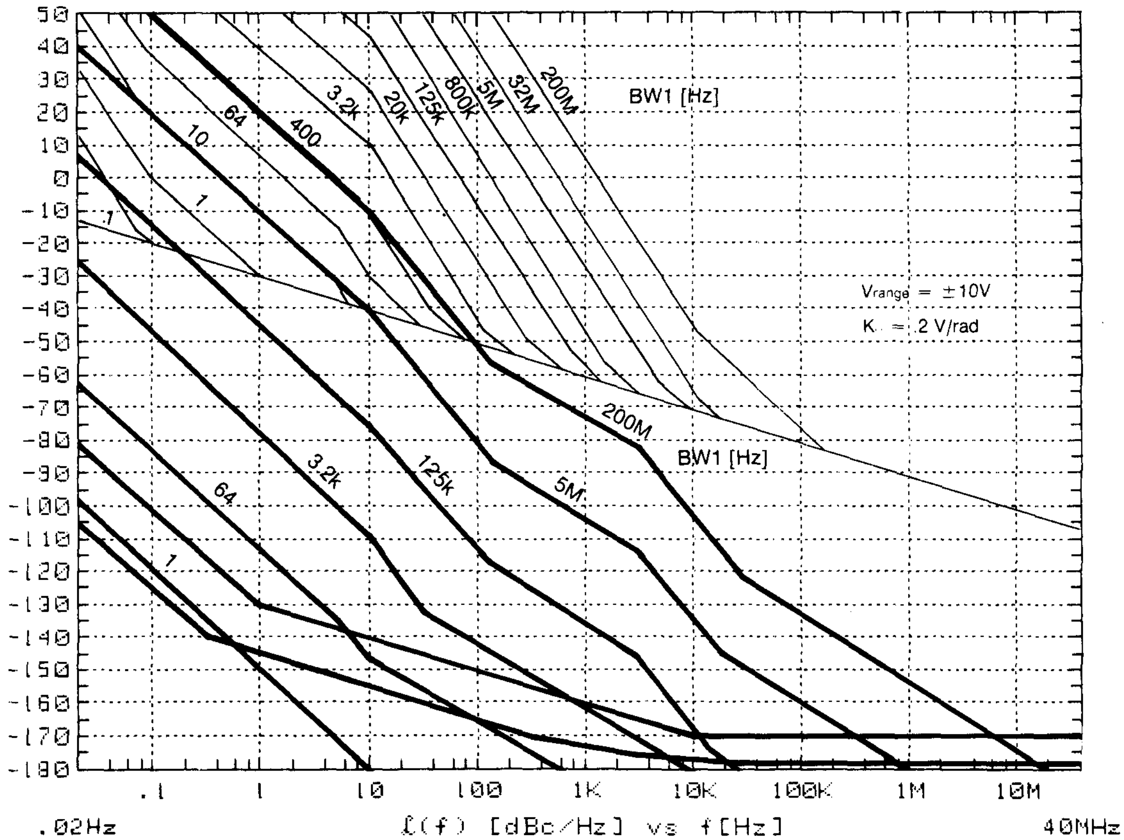
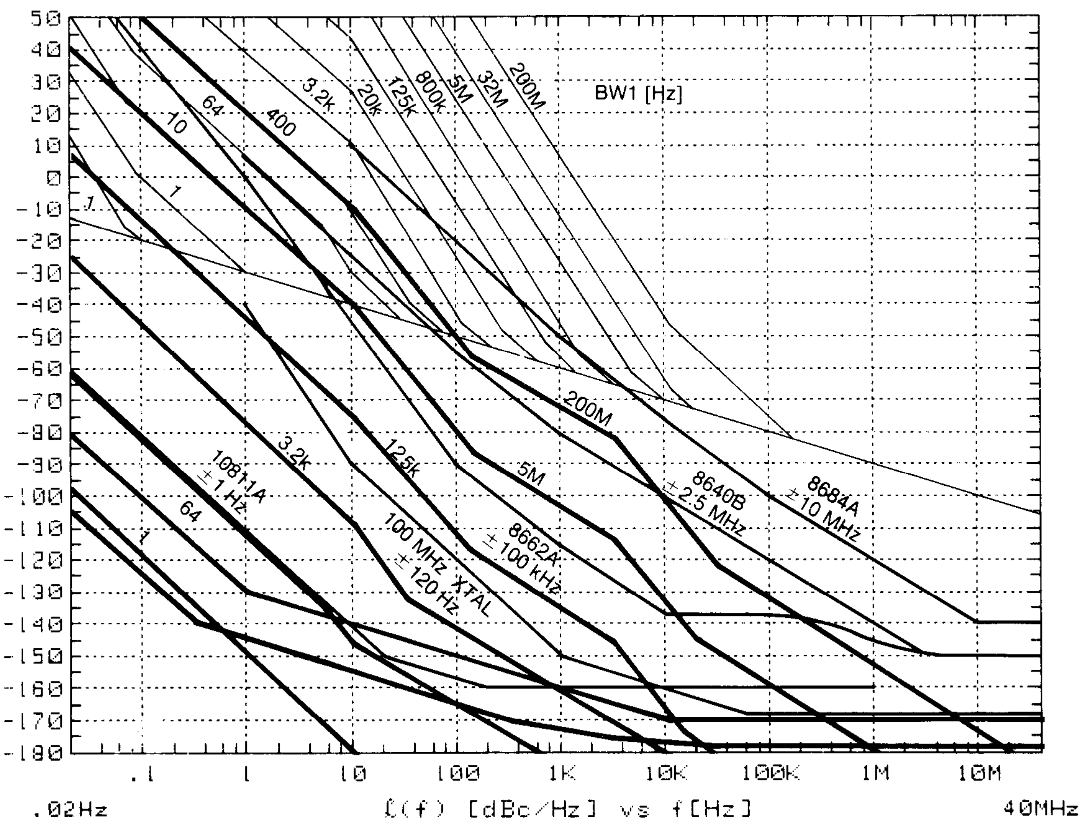
APPROXIMATE PHASE NOISE FLOOR vs. R PORT SIGNAL LEVEL



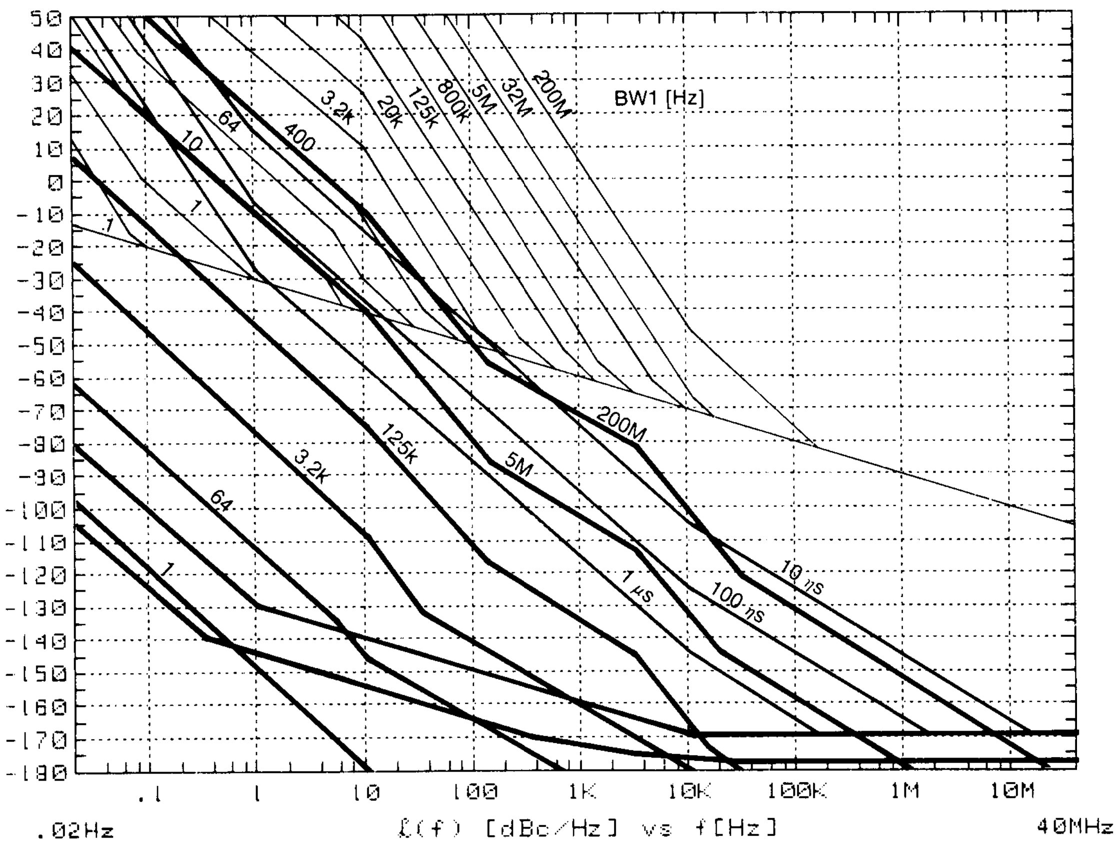
NOISE FLOOR AS SET BY 3047A VCO CONTROL PORT NOISE



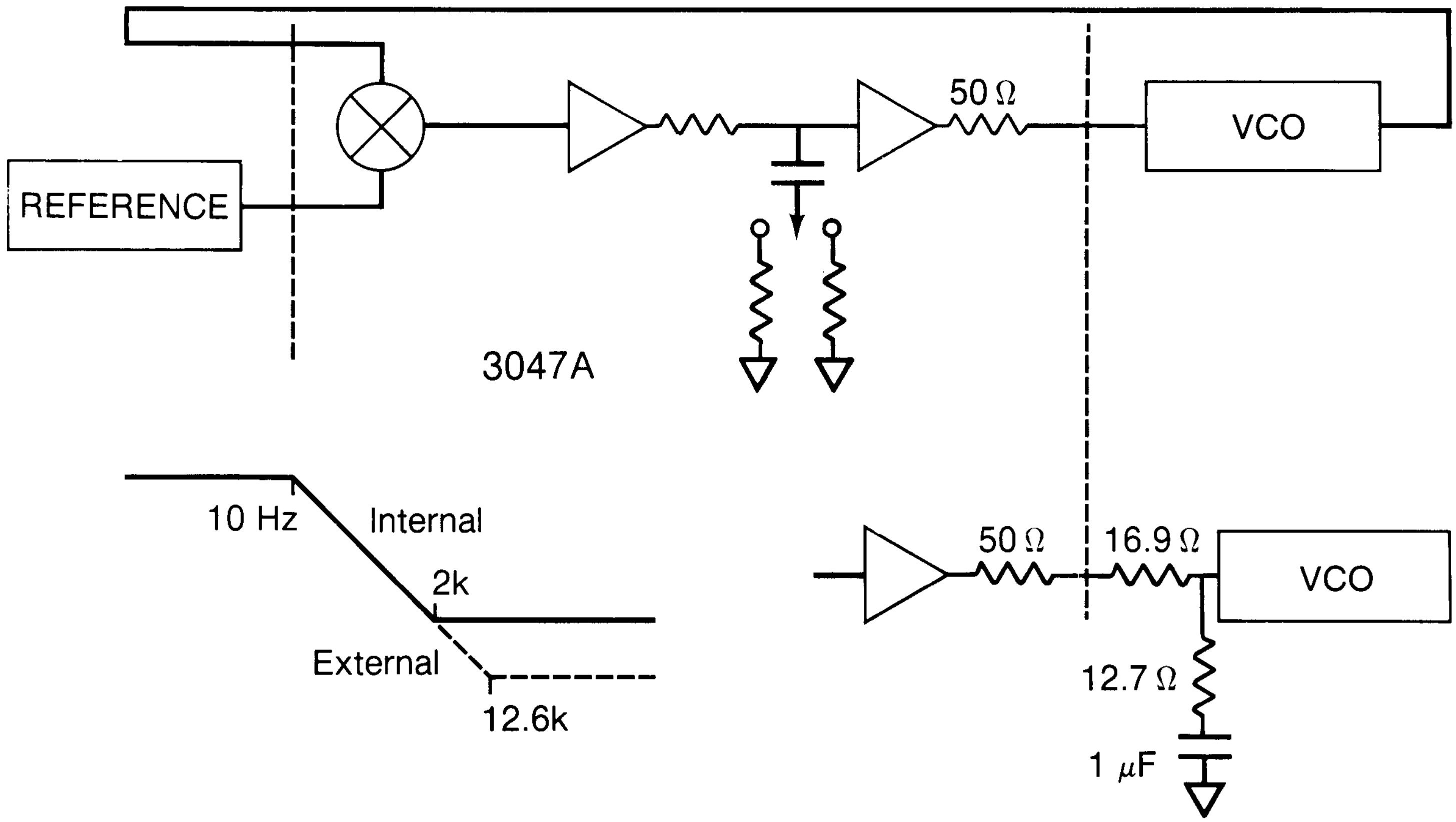
PHASE NOISE AND TUNING RANGE
OF SOME VOLTAGE-CONTROLED SOURCES



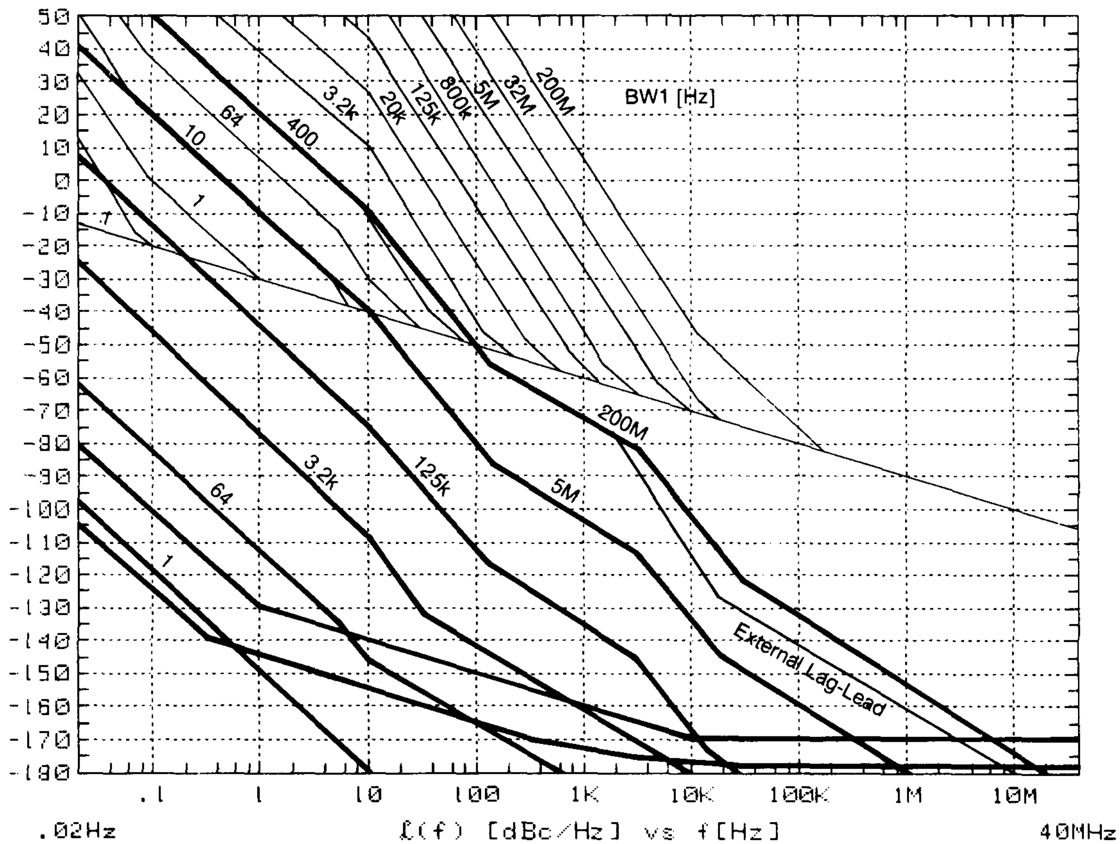
DELAY LINE DISCRIMINATOR SENSITIVITY COMPARED TO NOISE FLOOR SET BY VCO CONTROL PORT NOISE



USE OF AN EXTERNAL LAG LEAD TO REDUCE VCO CONTROL PORT NOISE

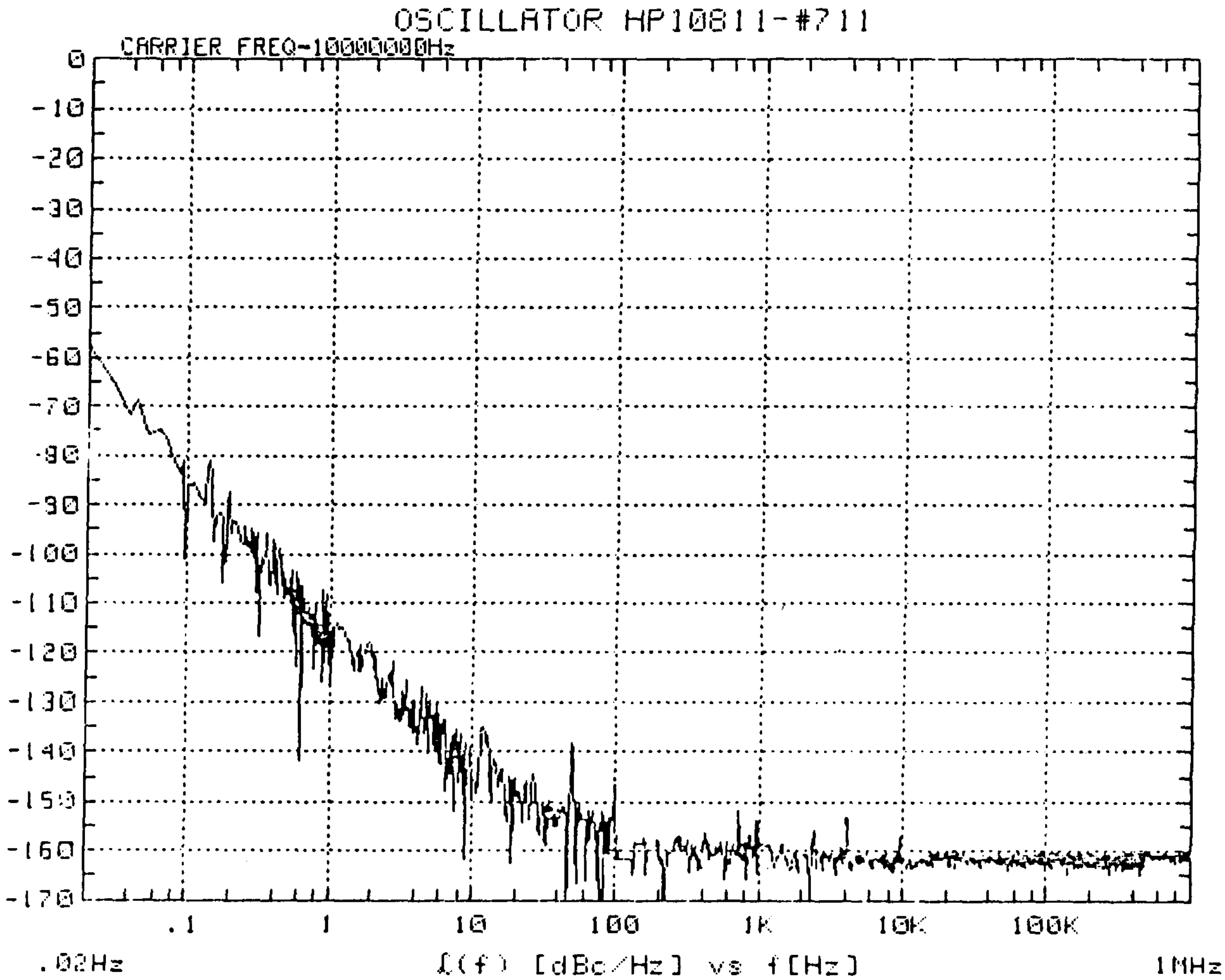


EXAMPLE OF VCO CONTROL PORT NOISE DECREASE WITH AN EXTERNAL LAG-LEAD FILTER

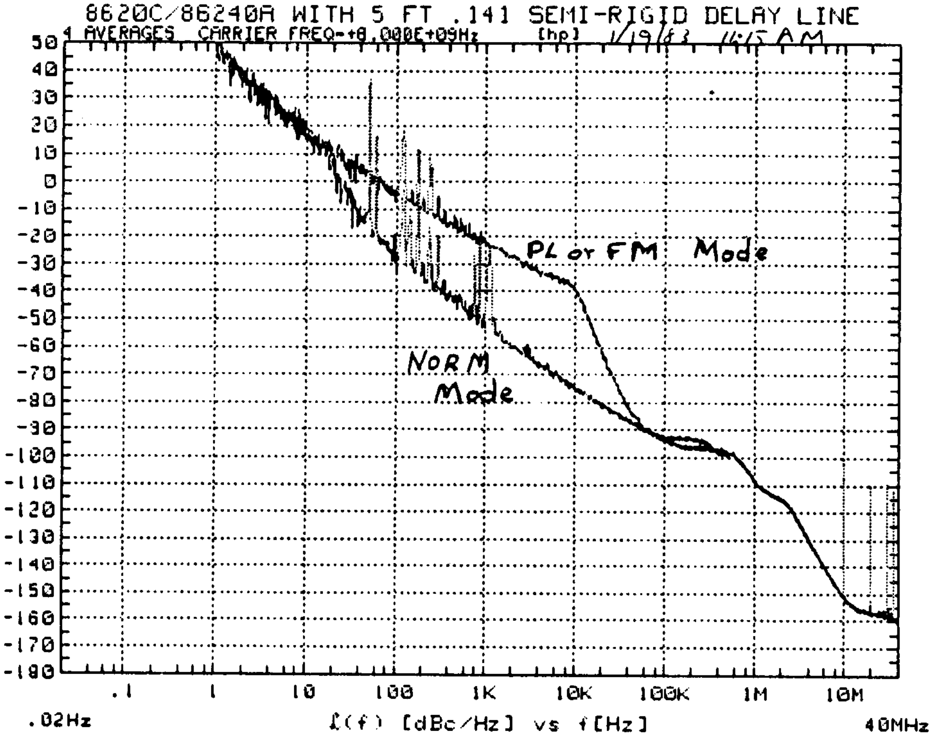


AGENDA

- BASIC PHASE NOISE MEASUREMENT CONCEPTS
- DIRECT SPECTRUM MEASUREMENT
- DEMODULATION TECHNIQUES
- PHASE DEMODULATOR
- RESIDUAL OR ADDED NOISE MEASUREMENTS
- SINGLE SOURCE MEASUREMENTS
- PHASE DETECTOR WITH TWO SOURCES
- REFERENCE SOURCE
- VOLTAGE CONTROLLED SOURCE TUNING REQUIREMENTS
- MEASUREMENT OPTIMIZATION
- ● MEASUREMENT EXAMPLES



Result of 3 Oscillator Comparison Software



Use 3047A

Phase Noise Analysis

Select k2 Phase Noise

Measurement Using a

Discriminator

If source cannot be

modulated to calibrate,

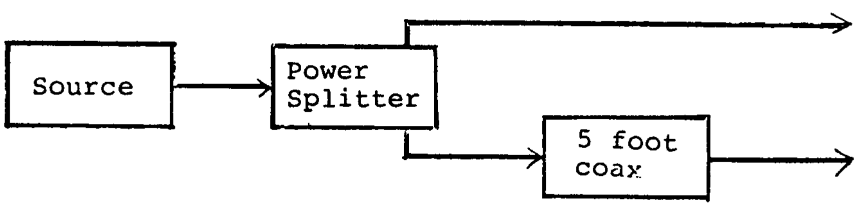
select User Entry of

Discriminator Constant

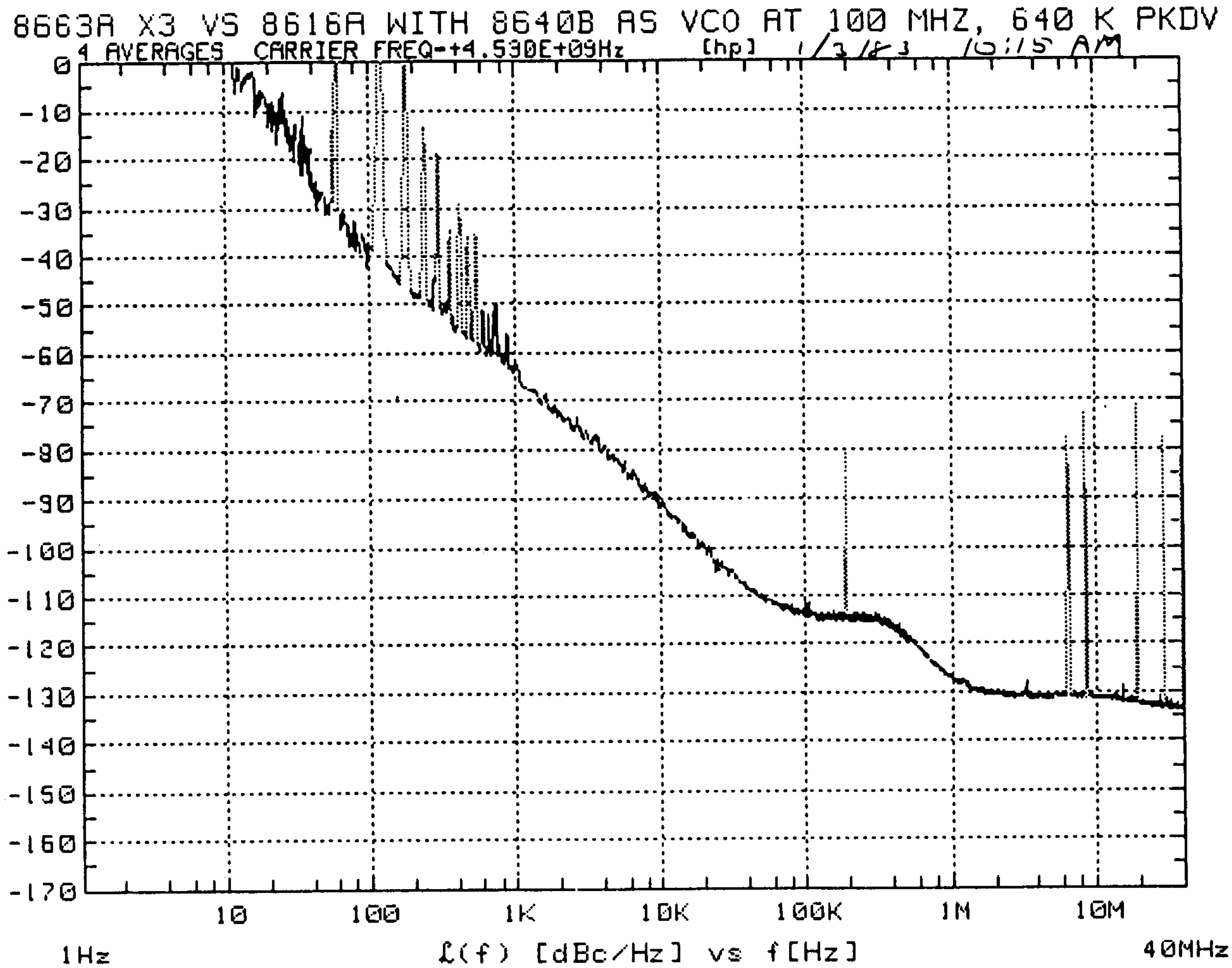
$k_D = 2\pi\tau k_\phi \quad k_\phi = .15v.$

$\tau = 5' \times 1.45$ nsec/ft $= 7.25$ nsec.

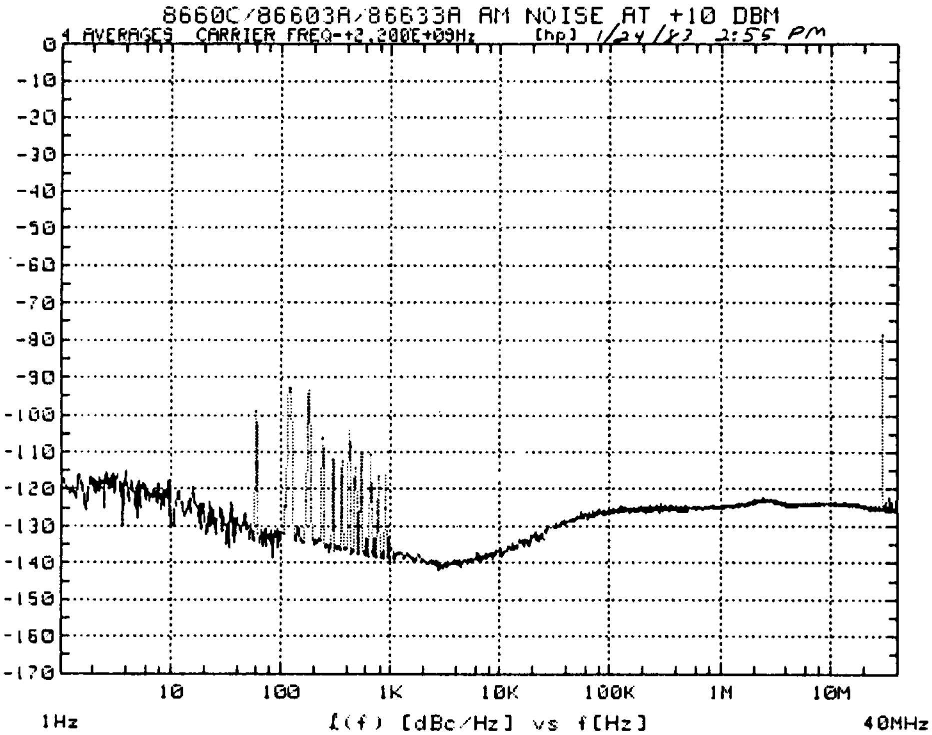
$K_D = 6.8 \times 10^{-9}$ volts/Hz.



3047A
Phase Detector Inputs
1.2 - 18 GHz



Measurement Using Phase Locked Interpolation Oscillator Technique



Use 3047A

Phase Noise Analysis

Select k1 - Phase Noise

Measurement without

Voltage Control

Select Calibration Option 3

FM or PM Spur

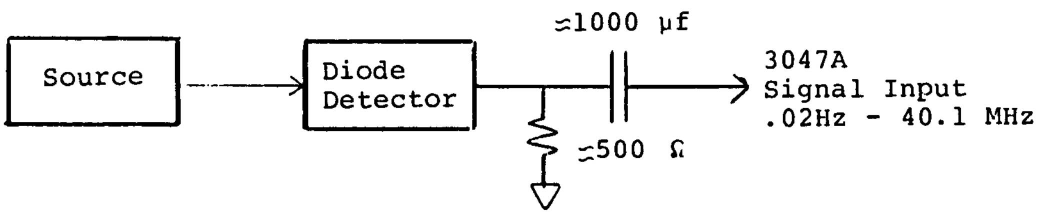
Calibrate with known

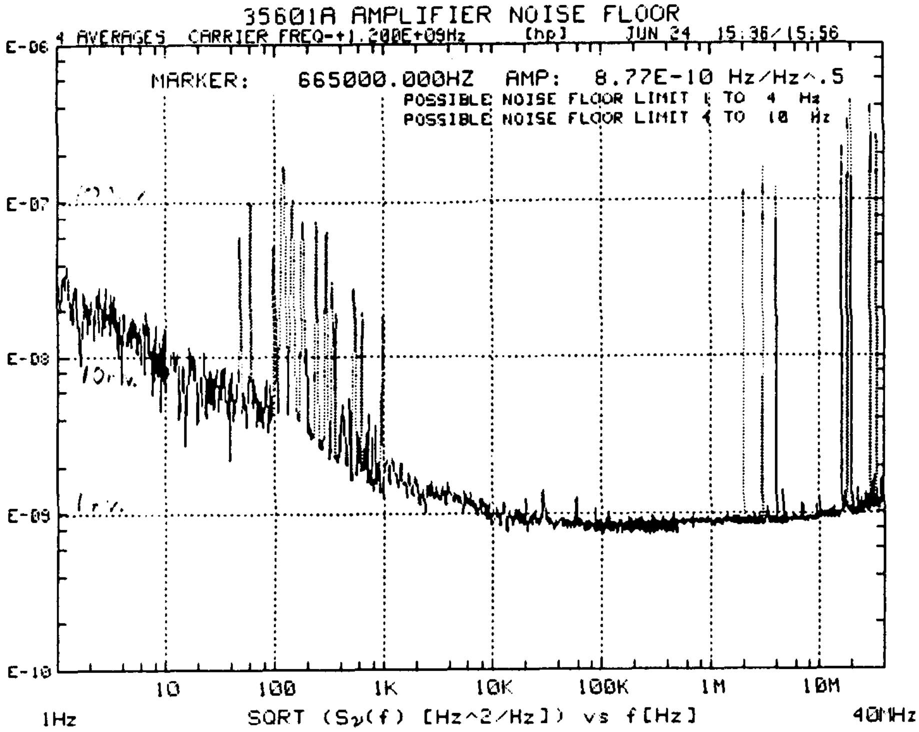
low level AM sidebands

from source under test

or from identical amplitude

and frequency sig. gen.





Use 3047A

Phase Noise Analysis

Select k2 Phase Noise Measurement Using a Discriminator

Select User Entry of Discriminator Constant

Let k_D = Total Gain from Amplifier Input to 3047A Input

Select $S_\nu(f)$ Plot and read as noise voltage in nv./√Hz