TANGENTIAL SENSITIVITY OF TUNNEL DIODE VIDEO DETECTORS

William F. Gabriel
NASA, Goddard Space Flight Center, Greenbelt, Maryland

ABSTRACT X66-33[illegible]1

Tunnel-diodes can be utilized as super-sensitive video detectors when biased in their negative resistance region such that they amplify the RF signal to be detected. Tangential sensitivities on the order of -70 dbm at a 10 mc video bandwidth are readily obtained at C-band. Such sensitivity makes this detector competitive with superheterodyne receivers which require a local oscillator, mixer, and IF amplifier. An approximate equation has been derived for calculating the tangential sensitivity of tunnel diode video detectors on the basis of their equivalent circuit constants and the voltage-current characteristic. Calculated performance curves of tangential sensitivity vs. RF bandwidth are compared against measured data for the case of a single-tuned RF passband shape. The conditions covered include RF load variation, temperature variation, and frequency variation. For a given tangential sensitivity, the bandwidth will depend upon the type of passband response that is designed into the RF input circuit, and a comparison is shown between the single-tuned response and a double-tuned response detector.

Author

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SUMMARY

An approximate expression may be derived for calculating the tangential sensitivity of tunnel diode video detectors[1,2,3], utilizing their equivalent circuit constants and the static V-I characteristics. Referring to Fig. 1, the voltage ν, across the diode junction may be approximated by the expression,

$$\nu \approx \frac{E_g}{Z} \left[Z - (R_g + R_s + jwL) \right] , \tag{1}$$

where Z is the usual series circuit impedance,

$$Z = \left[R_g + R_s + \frac{R_n}{1 + (wCR_n)^2} \right] + j \left[wL - \frac{R_n (wCR_n)}{1 + (wCR_n)^2} \right] . \tag{2}$$

Referring to Fig. 2, the non-linear segment of the curve between V_p and the operating bias point, V_b, may be approximated by a square-law relationship,

$$(I - I_p) \approx \frac{(V - V_p)^2}{2R_d \; V_o} \quad \text{if} \quad V_p < V < V_i \; , \tag{3}$$

where R_d is the resistance of the diode $({}^{dV}/_{dI})$ at the bias point, and $V_o = V_b - V_p$. From equations (1) and (3), one can show that the rectified current, I_r, is approximated by the expression,

$$I_r \approx \frac{(\nu \cdot \nu^*)}{4V_o \; R_d} = \frac{R_d \; |E_g|^2}{4V_o \; |Z|^2 \left[1 + (wCR_d)^2 \right]} \tag{4}$$

[redacted]

The tangential sensitivity condition occurs when the rectified current exceeds the rms video noise current by a factor of about 2.8, or roughly 9 db. If we insert this condition and convert E_g into available incident RF power, P_t, then we find that P_t is equal to,

$$P_t \approx \frac{1.4\ I_n\ V_o\left[1 + (wCR_d)^2\right]}{R_g\ R_d} \cdot |z|^2 \quad , \tag{5}$$

where the video noise current, I_n, may be approximated[3] by

$$I_n^2 \approx 2eI_bB_n + \frac{4KTB_n}{R_v} \tag{6}$$

$e = 1.6 \cdot 10^{-19}$ coulombs

I_b = dc bias current in amperes

B_n = video noise bandwidth

R_v = video circuit resistance

$4KT = 1.6 \cdot 10^{-20}$ watts per cycle.

Thus, equation (5) permits the calculation of tangential sensitivity for any diode whose equivalent circuit constants are known.

When comparing the tangential sensitivities of various diodes or detector mounts, the most practical variable to use is the RF bandwidth of the detector. Because of this, it is desirable to make performance graphs of tangential sensitivity vs. RF bandwidth. Equation (5) can be used for this purpose as it stands, but it becomes much more convenient to use after being manipulated for particular bandpass shapes. If we manipulate (5) for the case of a single-tuned bandpass shape, then we can obtain the following expressions for RF bandwidth and tangential sensitivity at resonance:

$$B \approx \left(\frac{1}{2\pi CR_d}\right)\left[\left(\frac{1+\sigma}{\alpha_o}\right) + 1\right] \tag{7}$$

$$P_t \approx 1.4\ I_n V_o \left(\frac{\alpha_o}{\sigma}\right)\left[\left(\frac{1+\sigma}{\alpha_o}\right) + 1\right]^2 \tag{8}$$

where $\sigma = \left(\frac{R_g}{R_s}\right)$

and $\alpha_o = \frac{\left(R_d/R_s\right)}{1 + (w_o CR_d)^2} = \frac{\left(R_d/R_s\right)}{1 - \left(1 + \frac{R_d}{R_s}\right)\left(\frac{f_o}{f_{ro}}\right)^2}$.

Here, the variable σ represents the RF loading normalized to the series loss resistance R_s; and the variable α_o represents the RF negative resistance of the diode, also normalized to R_s. Note that α_o takes the sign of R_d and is therefore negative, and that α_o approaches unity as the resonant frequency f_o approaches the resistive cut-off frequency f_{ro},

$$f_{ro} = \left(\frac{1}{2\pi CR_d}\right)\sqrt{\left|\frac{R_d}{R_s}\right| - 1} \tag{9}$$

Several graphs have been calculated from these expressions for a particular diode, the MS1012, for which R_d = -370 ohms, R_s = 5.4 ohms, C = 0.5 P_f, V_o = 0.03 volts, I_b = 0.250 ma, R_v = 230 ohms, and B_n = 10 mc.

Figure 3 shows a comparison of the calculated and measured tangential sensitivity under the condition of variable RF loading (variable σ), at a single-resonance frequency of 5.9 Gc. It will be noted that the two curves are quite similar in shape, but that a 5 db discrepancy exists between calculated and measured P_t values.

Figure 4 shows a comparison of the calculated and measured curves under the condition of temperature variation. For the calculated curve it was assumed that R_d drifts at the rate of 0.4 percent per degree centigrade. It will be noted that the temperature drift is considerable when the detector is adjusted for narrow bandwidths, so that one must employ either temperature regulation or temperature compensation techniques if high-sensitivity operation is desired.

Figure 5 is a comprehensive detection graph on which are drawn two families of curves. The solid-line curves are for constant frequency ($^f/_{f_{ro}}$) and variable RF loading (σ), and they demonstrate the desirability of operating well below f_{ro}. Detection sensitivity falls off very rapidly at narrow bandwidths when f_{ro} is exceeded. The dashed-line curves are for constant σ and variable frequency, and they demonstrate the desirability of operating at a high value of R_g. Detection sensitivity suffers when R_g becomes significantly smaller than R_s because the loss of power in R_s increases as R_g decreases.

The single-tuned bandpass shape performance exemplified in Figures 3, 4, and 5 results in the least amount of bandwidth for a given tangential sensitivity. It is possible to increase this bandwidth by applying elementary filter design principles in the RF input circuit so as to realize a more optimum bandpass shape. For instance, Figure 6 illustrates the improvement that was obtained by utilizing a double-tuned bandpass characteristic.

ACKNOWLEDGEMENT

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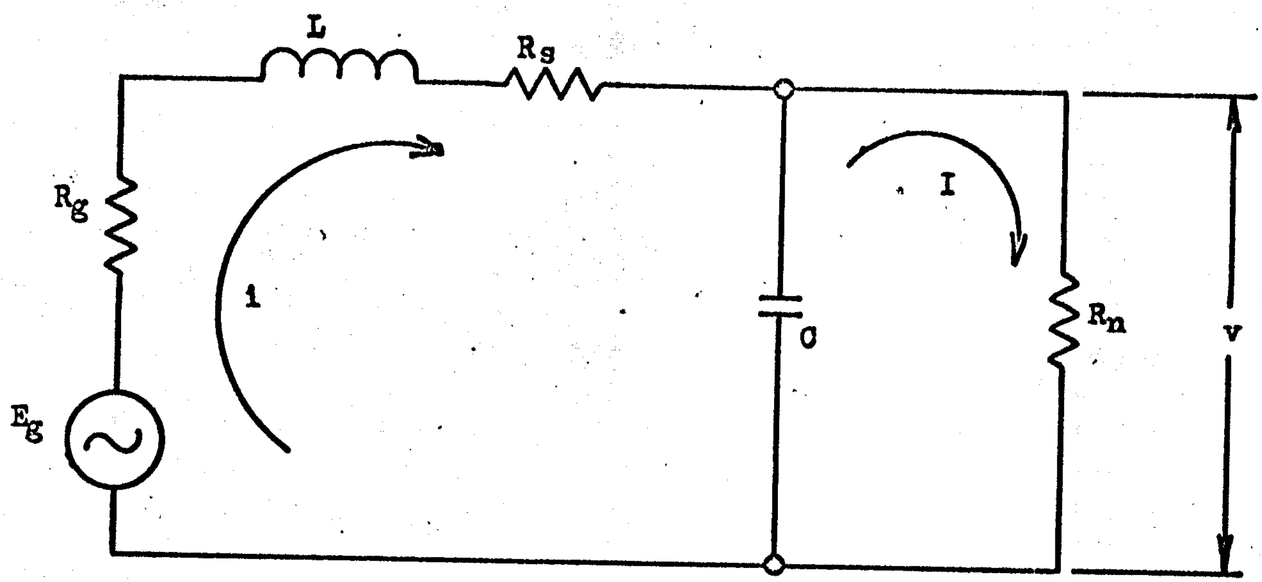
FIGURES

Figure 1



R_n - nonlinear junction resistance, (dV/dI)

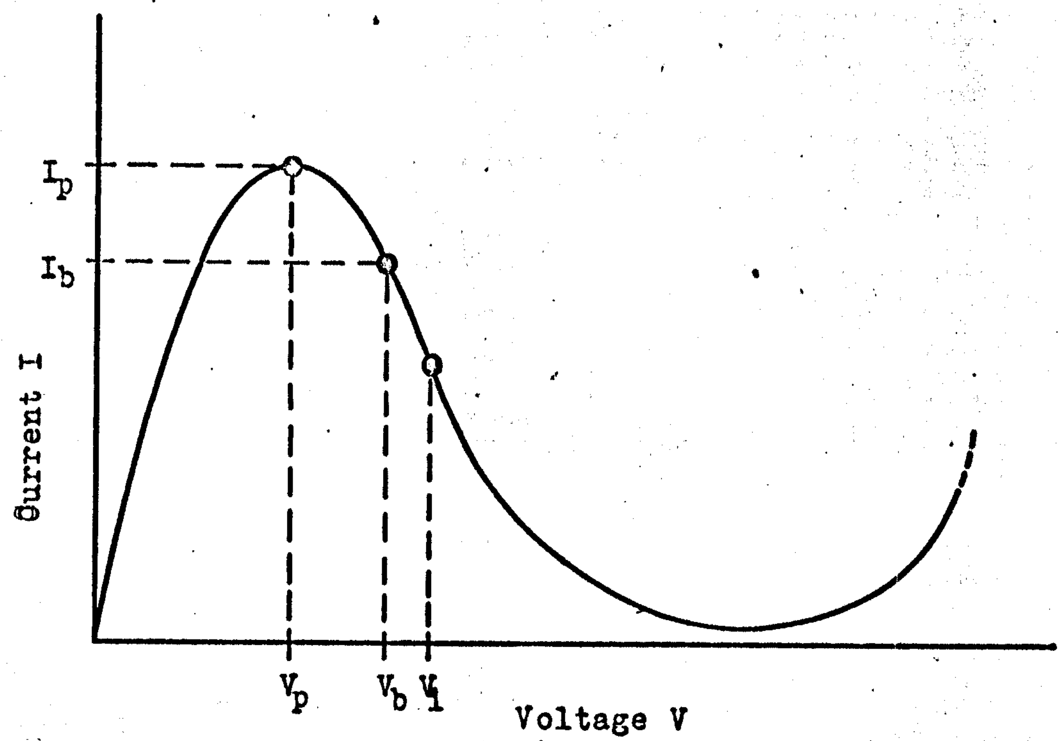
C - junction capacitance of diode

R_s - series resistance of diode

L - equivalent RF circuit inductance

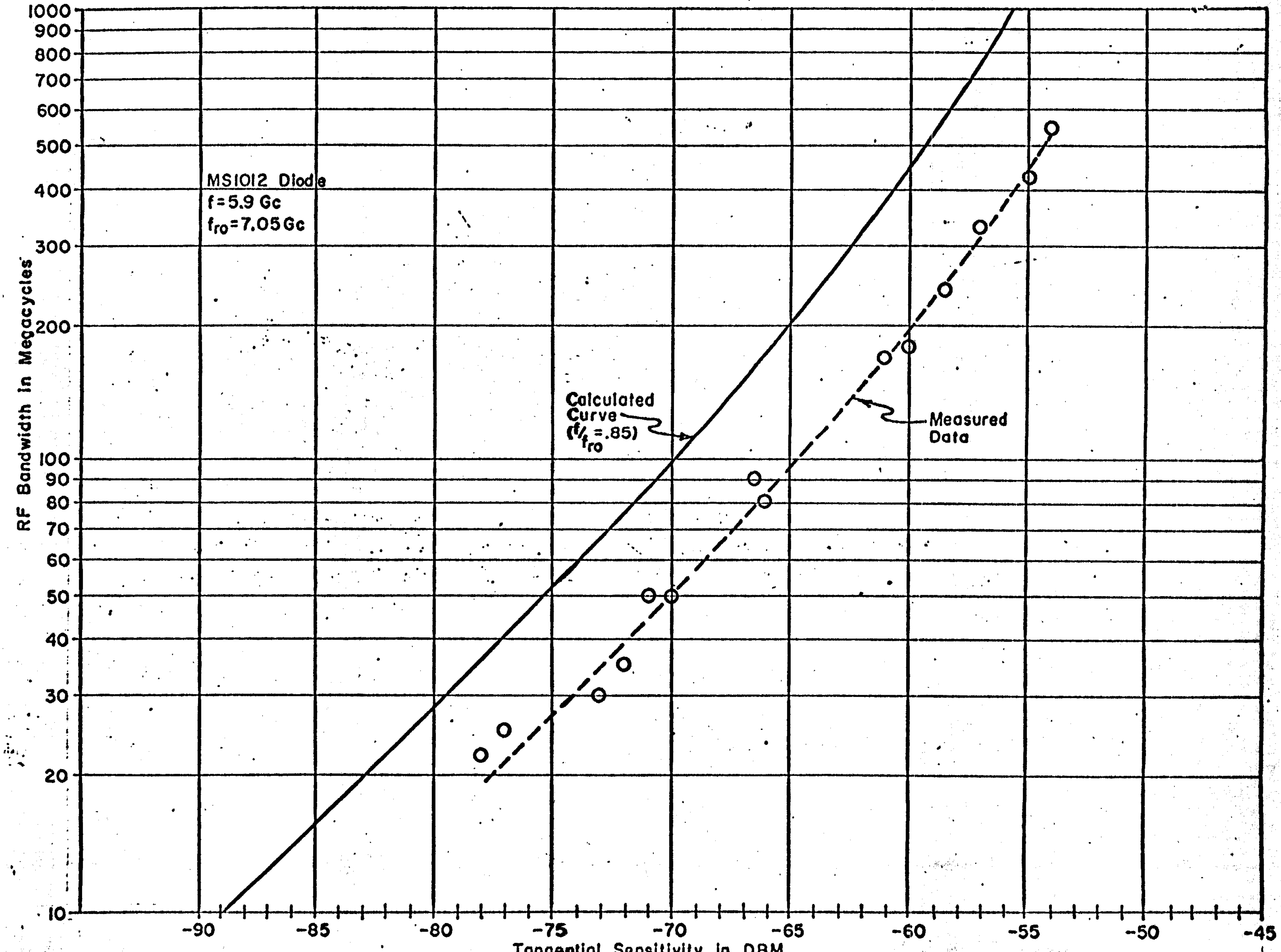
R_g - equivalent RF circuit resistance

Figure 2



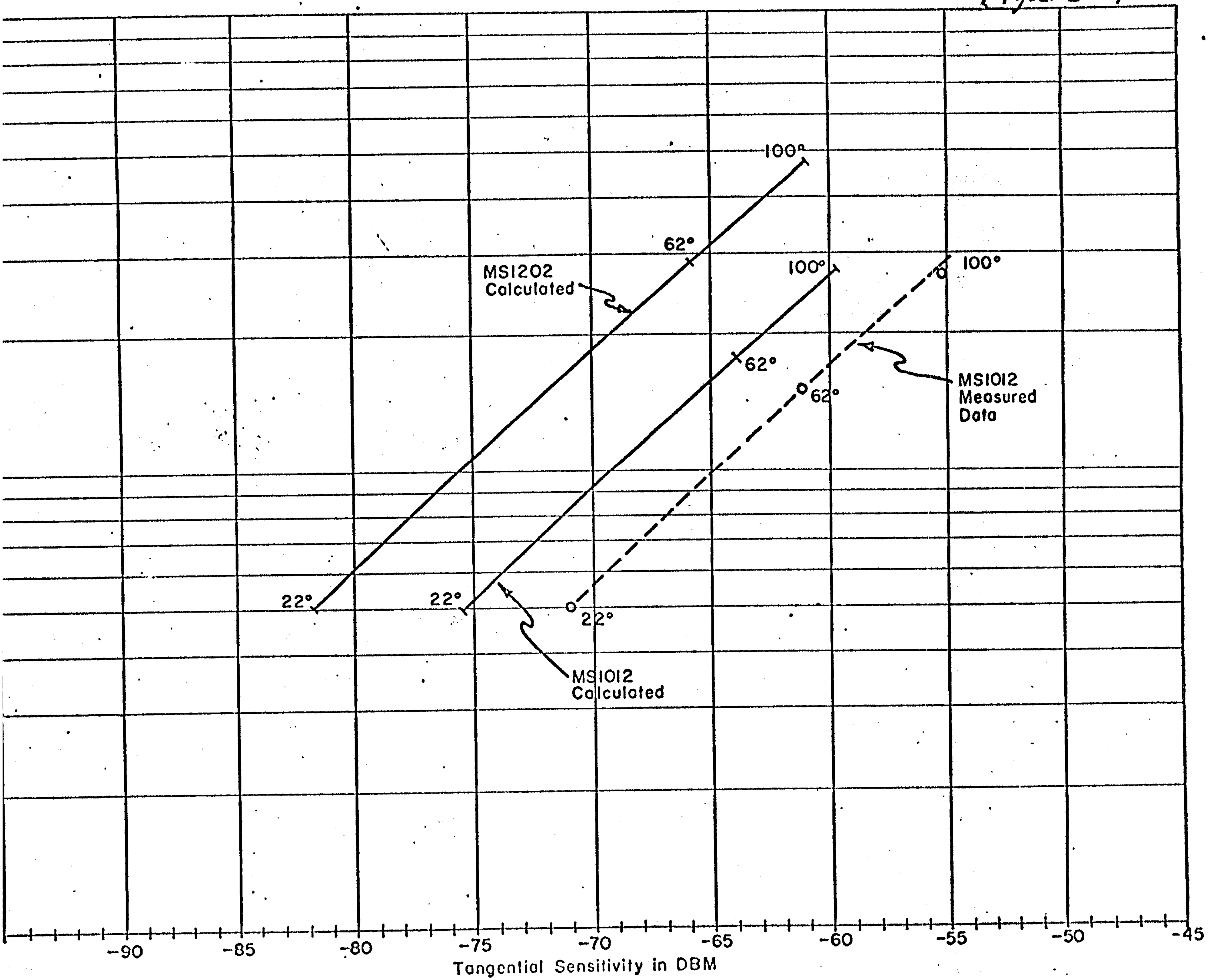
Voltage-Current Characteristic for Nonlinear R_n

Figure 3

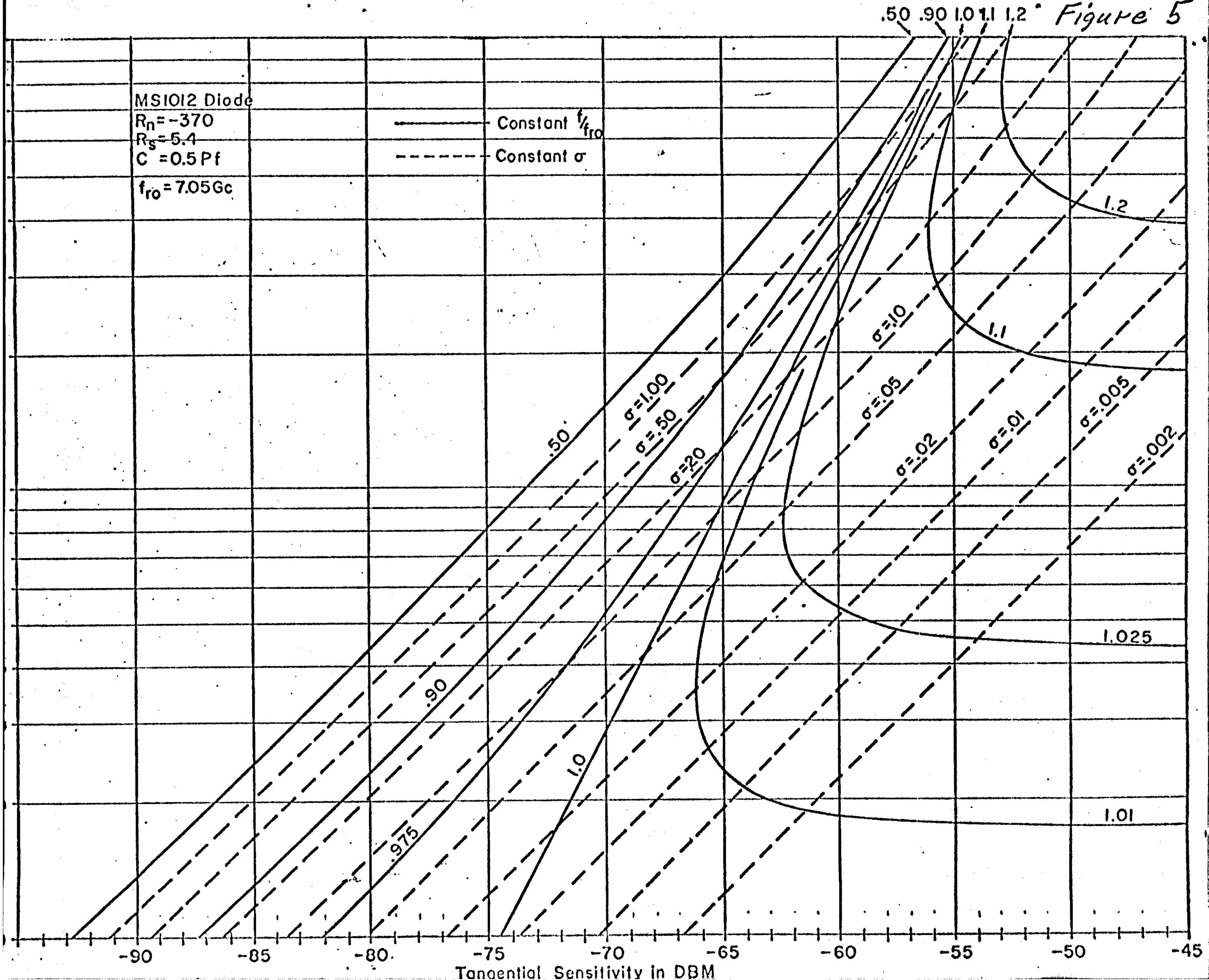


RF Bandwidth in Megacycles
Tangential Sensitivity in DBM
MS1012 Diode
f=5.9 Gc
f_{ro}=7.05 Gc
Calculated Curve (f/f_{ro}=.85)
Measured Data
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
-90
-85
-80
-75
-70
-65
-60
-55
-50
-45

Figure 4



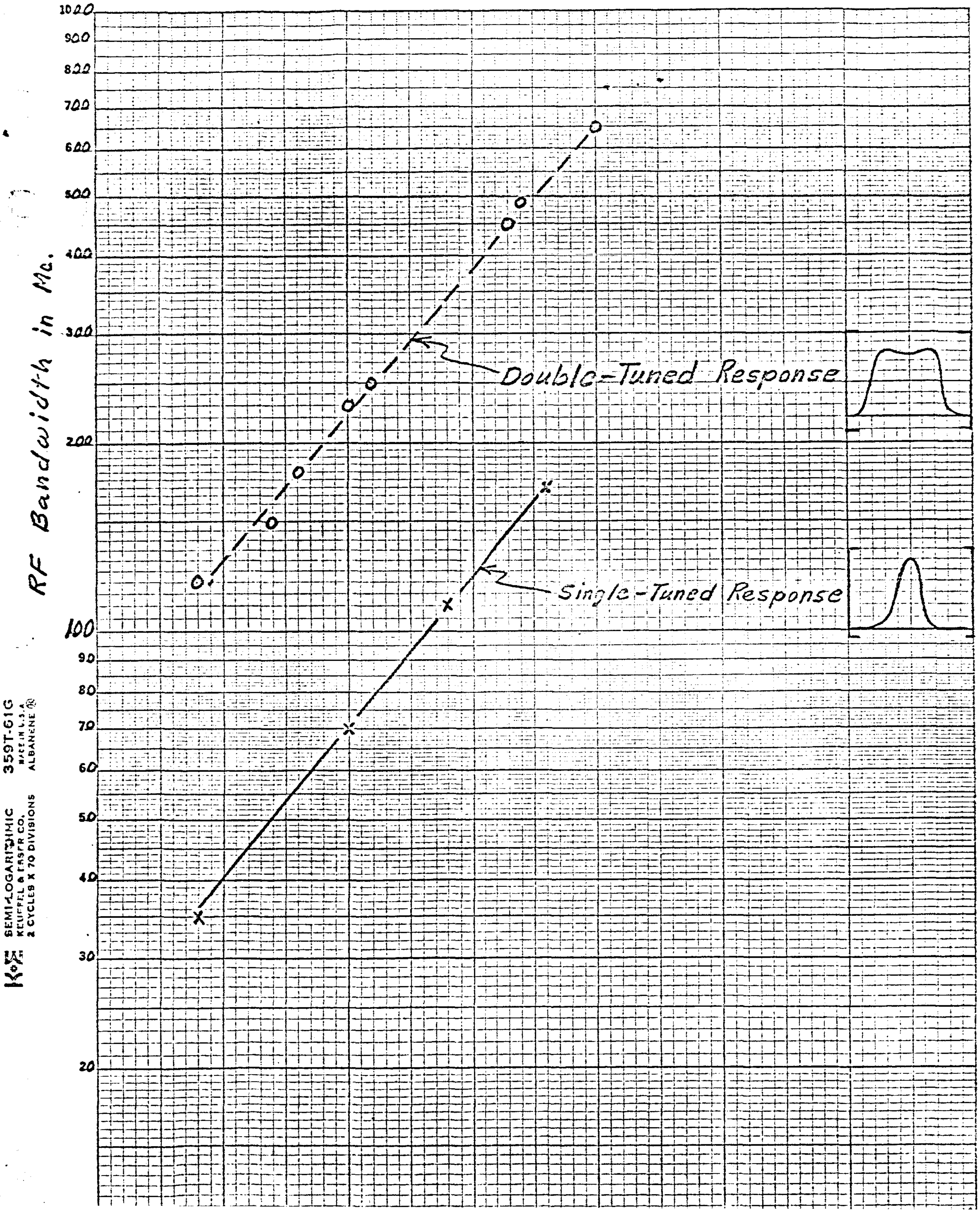
100°
62°
22°
MS1202 Calculated
MS1012 Calculated
MS1012 Measured Data
-90
-85
-80
-75
-70
-65
-60
-55
-50
-45
Tangential Sensitivity in DBM



.50 .90 1.0 1.1 1.2
MS1012 Diode
Rn=-370
Rs=5.4
C =0.5 Pf
fro=7.05Gc
Constant f/fro
Constant σ
1.2
1.1
σ=.10
σ=1.00
σ=.50
σ=.20
σ=.05
σ=.02
σ=.01
σ=.005
σ=.002
.50
.90
.975
1.0
1.025
1.01
-90
-85
-80
-75
-70
-65
-60
-55
-50
-45
Tangential Sensitivity in DBM

Figure 5

Figure 6


RF Bandwidth in Mc.
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
Double-Tuned Response
Single-Tuned Response
359T-61G
SEMI-LOGARITHMIC
2 CYCLES X 70 DIVISIONS