A Switch-Detector Circuit

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Summary—**Crystal circuit is used wherein switching is accomplished by varying dc voltage across a crystal. Impedance of crystal plus its mount varies from low inductive to high capacitive value. Maximum attenuation frequency of high-pass, series *m*-derived filter varies with change of parallel inductance or capacitance. If crystal is placed across parallel capacitance, and its bias varied, input impedance of filter is changed. As a result, attenuation vs frequency characteristics are varied. Operating parameters of switch are: frequency, 500–1,000 mc; bandwidth, 20 mc; switching, >55 db; average insertion loss, 2 db; switching time, <$\frac{1}{2}$ μsec; bias voltage, between −0.6 and +0.6 volts. This unit finds application in radar jamming problems, as well as a low power modulator for rf signals.**

THERE HAS, in the past, been some interest in the subject of crystal diode switching. This art gives a method of constructing a small and lightweight switch which is fast acting and requires low power for operating. Crystal diode switches are usually of two basic types; narrow and broad-band.[1] This paper shall concern itself principally with the narrow-band type.

The basic property of the crystal which allows its application in a switch is the change of impedance with a change of dc bias applied across the diode. This particular subject has received much attention in basic works on crystals.[2-4] As an initial step to the problem of crystal switching, a series of crystals and assorted mounts were tested to determine the relationship of crystal impedance and direct-current bias voltage. A typical plot is shown in Fig. 1. A section of a Smith Chart is shown in which the impedance of a 1N23B crystal diode is plotted with a variation from +1.5-volts to −1.5-volts bias. These measurements were made at a frequency of 750 mc. Crystal output was shunted with a by-pass capacitor presenting a low impedance to rf. Presence of capacitor, crystal, and mount changes curve from capacitance to inductance as crystal resistance is changed.

The problem, therefore, resolves itself into finding the best method of employing this impedance change to develop a switch with high attenuation on the "off" position, and low insertion loss in the "on" position. The circuit should also be rather unaffected by a change in crystals and small changes in bias voltage.

Considering only narrow-band switches, it is evident that three basic circuits or combinations thereof may be employed: band-pass, high-pass, and low-pass filters. Some work on band-pass switches—employing a shift in resonant frequency by varying impedance of a crystal—has been done at Sperry Gyroscope Company. By employing two crystals in the shunt arms of a coaxial line, a dynamic switching of greater than 24 db (maximum to minimum insertion loss) was obtained with a useable pass band of 10 mc at 330 mc. In this switch it is necessary to have the two stubs (with crystals) present an exact impedance in the line in order to overlap the response curves. The circuit, therefore, was rather sensitive to a change in crystals.

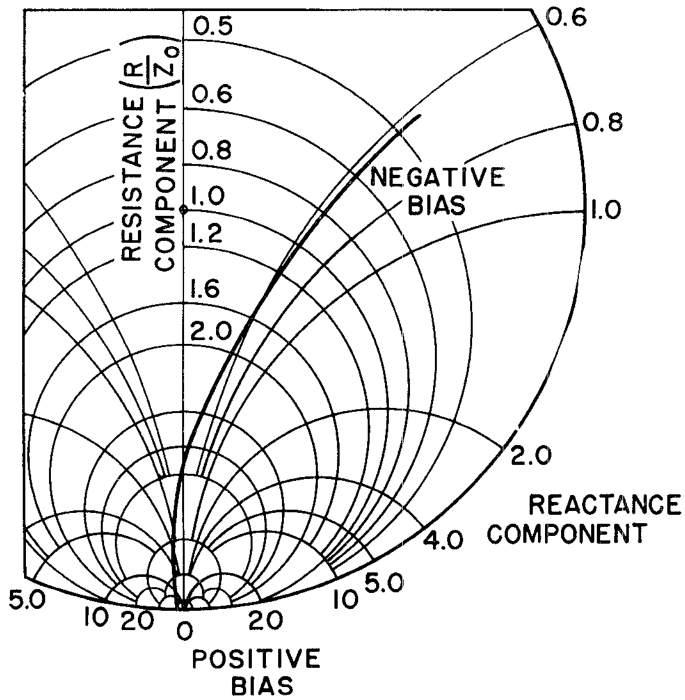

Fig. 1—Smith chart of 1N23 crystal impedance.

Low-pass filter switches have been built by the author and at the Applied Electronics Laboratories. Since these filters have many of the same characteristics of high-pass filters, the two cases will be treated simultaneously.

High- and low-pass shunt *m*-derived circuit diagrams are shown in Fig. 2. The associated attenuation curves are shown below each circuit. The most obvious place for the crystal to be placed is across the shunt capacitor, since for detection the crystal is across a voltage maximum. The presence of the crystal affects the frequency of maximum attenuation. Varying the bias causes a shift in the resonant frequency of the shunt element.

Fig. 3 shows a typical curve of plus and minus bias plotted in terms of attenuation versus frequency. By employing two filter sections in series, a much higher switching action is obtained. Fig. 4 shows a curve of insertion loss versus dc bias voltage at 750 mc. Fig. 5 shows a curve of insertion loss versus crystal current. For these curves, two sections were used.

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[1] D. J. Grace, "A Microwave Switch Employing Germanium Diodes," Applied Electronic Laboratory Tech. Report 26, Stanford University, January 17, 1955.

[2] H. A. Bethe, "Theory of Boundary Layer of Crystal Rectifiers," MIT Rad. Lab. Rpt. #43-12.

[3] F. Seitz and S. Pasternack, "The Principles of Crystal Rectifiers," University of Penn. D1-102.

[4] H. Huntington, "R. F. Impedance of Crystals with Standard Polarity," MIT Rad. Lab. Report 53, October 19, 1942.

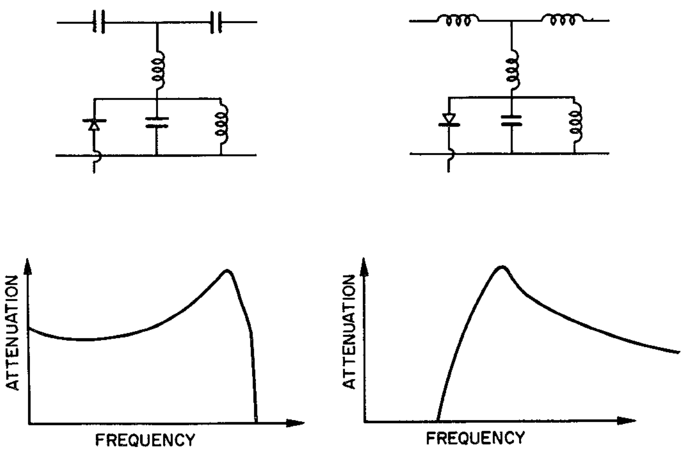

Fig. 2—High- and low-pass filter sections and related curves.

The bandwidth over which switching exceeds 40 db was measured to be 30 mc at 750 mc. The maximum switching action was greater than 65 db for a limited frequency range. The insertion loss of the double high-pass filter switch was 2.5 db over the 30 mc. Several other combinations of circuits were developed. A double low-pass circuit had a switching action of 43 db, with an insertion loss of 1.0 db. These circuits have a rather narrow bandwidth. To rectify this difficulty a high- and low-pass filter switch was constructed which has a bandwidth of 50 mc at 750 mc. These switches are constructed so that the maximum attenuation point of the high-pass filter switch is increased in frequency, while the low-pass switch is decreased. It might be expected that the switching action for this tandem circuit would be somewhat less than the double high- or low-pass circuits, since the curves overlap only at the center of the band. Average switching was 34 db measured at 750 mc.

It has been found that the highest switching occurs with a high front-to-back ratio crystal. A variation of crystals all having a high front-to-back ratio produced a change in maximum insertion loss position of approximately 2 db.

A square wave was employed as a biasing voltage to measure speed of switching. The continuous-wave rf input signal was therefore modulated in a square wave. The input bias voltage and output rf voltage were compared, and switching time computed. Due to the inadequate square-wave source, only an upper limit was established less than one-half microsecond. The higher the resistance of the crystal, the greater the switching time should be, since transients are present.

As the Smith Chart plot pointed out, the external circuit controlling the bias has a great effect on the switching range as well as the switching time. Together with these factors are the detection characteristics, which also must be considered. A 1.5-microhenry rf choke is employed for a dc return. This should be large enough to present a high impedance to the rf energy, but small enough to allow rapid switching. In general, this does not affect the detection characteristics. A by-pass capacitor is placed on the rectified signal to present a low impedance to rf. Fig. 6 shows a plot of crystal sensitivity for various crystals. These curves are for an average set of crystals; the high and low curves represent the spread.

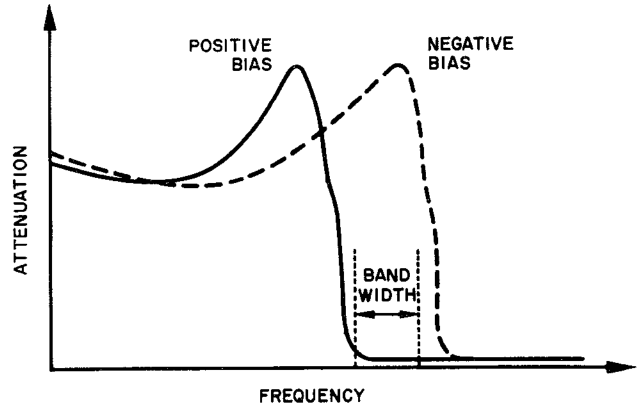

Fig. 3—Effect of crystal bias on frequency response.

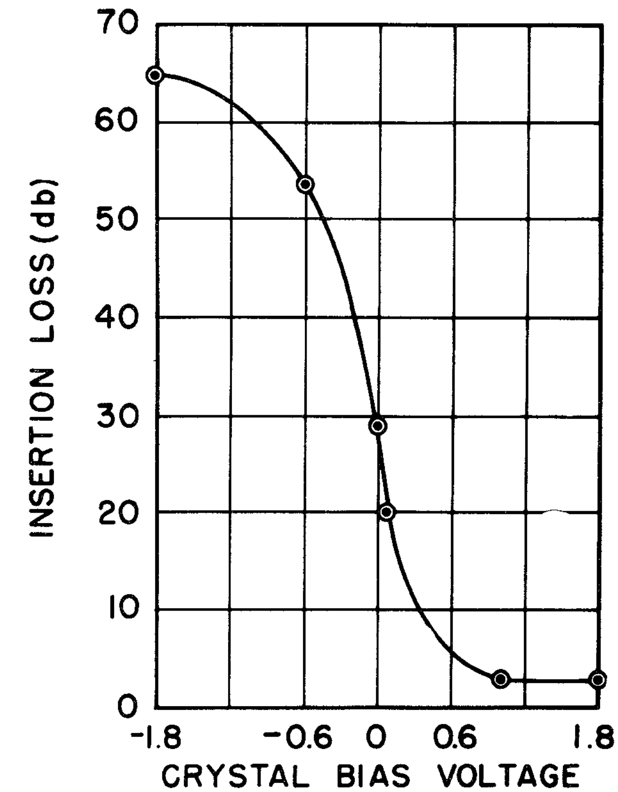

Fig. 4—Insertion loss vs crystal bias voltage for dual section switch with 1N23B crystals.

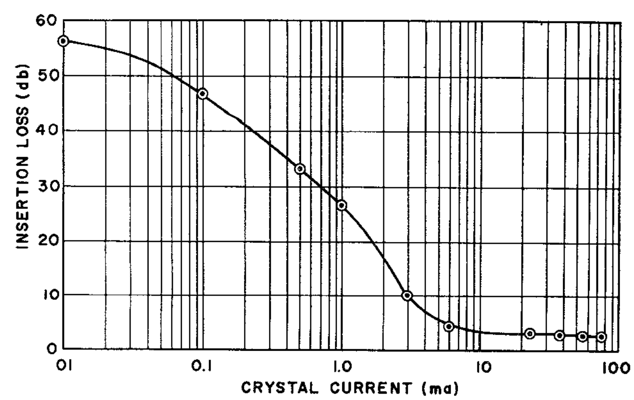

Fig. 5—Insertion loss vs. crystal current.

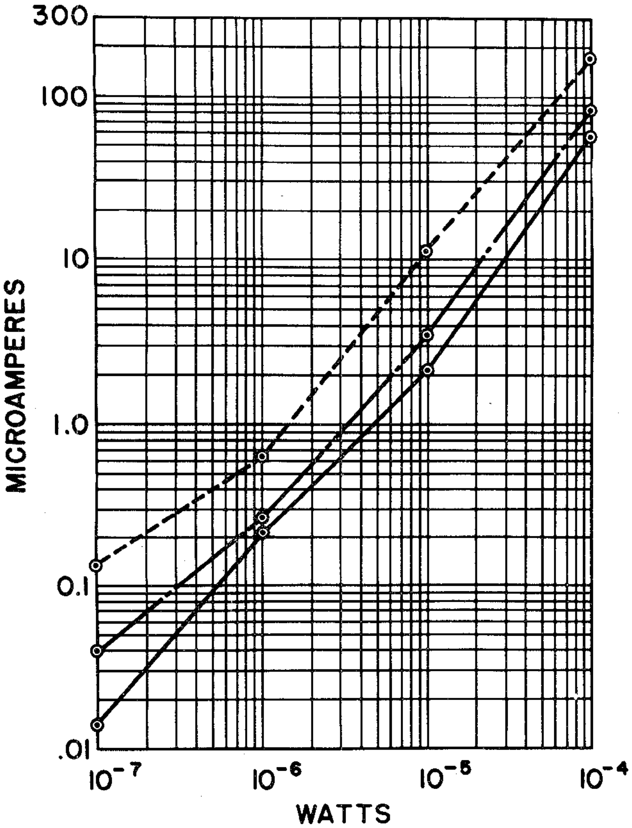

Fig. 6—Sensitivity of detector portion of switch showing two extremes and average crystals.

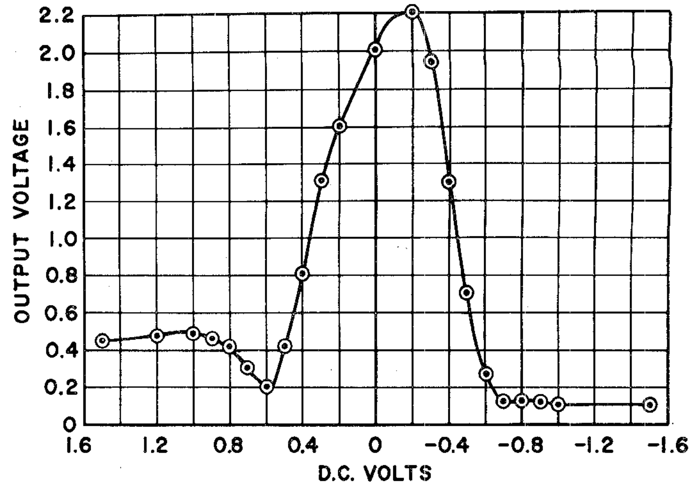

Fig. 7—Variation of detected output vs bias.

The voltage output with a 50-mw of rf input signal is approximately 3.8 volts. Only a single crystal is used for detection in the double crystal units.

The detector output is the same as the bias input, and various methods must be employed to separate the two voltages. A plot of crystal detector output versus bias voltage is shown in Fig. 7. It is seen that for efficient detection the bias must be very close to zero voltage. Since the bias voltage varies from +1.5 volts to −1.5 volts (somewhat lower voltages give similar results—+0.7 and −1.0 volts) and the detected voltage is close to four volts, the external switching circuit may employ an amplitude discriminator.

These switches were required to be small and light in weight. Lumped constant methods were the only practical means for construction. A photograph of a double high-pass switch-detector is shown in Fig. 8. There are methods for tuning switch to allow for variation of crystals and for limited change of frequencies. This switch measures $1\frac{1}{2}\times2\frac{1}{2}\times1\frac{1}{4}$ inches. The rf input and outputs are at the ends of the can, and the detector output-bias input connector is at the side. Lumped constant elements are almost at the maximum practical frequency at 1,000 mc; hence, the response at higher frequencies is very poor.

Other methods for construction were examined. Printed circuits offer no simple means for tuning. Strip lines were employed to construct a switch at 6,000 mc. A slightly different principle was employed—that of detuning a hybrid ring. This switch, of course, had a much narrower bandwidth than the lower frequency circuits, and a switching of 28 db was obtained with two crystals.

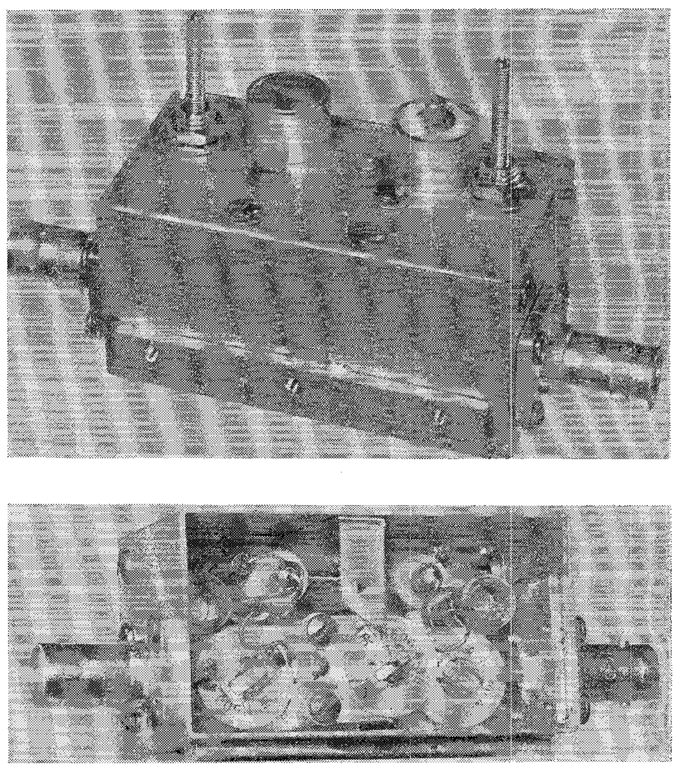

Fig. 8—Dual crystal unit of crystal switch-detector.

Other means of switching (nondetecting) were investigated; the mechanical switch and the gas discharge switch were extremely high compared to crystal switching. The crystal switch is small and lighter than either the gas or the mechanical, the latter having a low switching speed.

The main disadvantage to the crystal switch is its low power handling capacity, which is limited to the power limits of the crystals.

An important use for this crystal switch detector is in an automatic-frequency meter. It may also be used in radio relay links, as well as a low power rf modulator.