ITT Ft.Wayne

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DISCUSSION OF THE DESIGN OF BAND PASS FILTERS

1.0 INTRODUCTION

Early in 1958, this laboratory developed a microwave receiving system which included a microwave filter and detector mount. This filter represented what, at that time, seemed to be the best compromise in a filter-crystal mount design that would meet the physical and electrical requirements. Now, having a need for a very similar system, it is desirable to look back upon the previous design to see what improvements can be made or whether a complete change in the basic design would be advantageous.

Before discussing the design of the filter, a few paragraphs are devoted to the design limitations imposed by the detector crystals.

2.0 DETECTOR CRYSTAL DESIGN LIMITATIONS

A crystal has an equivalent circuit which depends upon both the crystal mount and the applied dc bias current. Considerable data has been recorded on the MA-408 and IN23E crystals in various coaxial detector mounts to determine the impedance characteristics and the spread in the characteristics of several samples of a given crystal type. Special data was recorded for this discussion on a filter fabricated during the earlier program. The relative frequency response has been recorded for several crystals with applied bias current as a parameter while maintaining a constant r.f. signal level into the filter. Figure 1 is the relative frequency response of the filter-detector operating at zero applied d-c bias and containing any one of six MA 408B crystals. Since new crystals were not available for this test, it was necessary to use crystals of virtually unknown history. The points indicated in Figure 1 are the relative loss at the peaks and valleys of the response curves. The output of the various crystals is located within the shaded area between the limit curves. It should be noted that at the lower frequency cut-off (f_1) the variation in the detected output from crystal to crystal is 10.3 db with zero bias.

Figure 2 indicates that a bias current of 10 microamperes improves the sensitivity considerably, and the variation from crystal to crystal reaches a maximum of 4.6 db slightly below f_1; however, within a particular pass band of f_1 to f_2, the maximum variation is 2.5 db. With the bias current increased to 25 microamperes, the crystal spread within the pass band is a maximum of 1.8 db at a frequency near f_2 as shown in Figure 3. The average sensitivity over the pass band at 25 microamperes bias is not as good as for 10 microamperes bias because the rectification efficiency for most detector crystals is optimized in the vicinity of 10 microamperes bias. However, the minimum sensitivity at 25 microamperes is no less than the minimum sensitivity with 10 microamperes bias current.

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Figure 4 shows an even greater reduction in spread with 50 microamperes bias. The data spread is 1.2 db or less over most of the pass band. The application of 50 microamperes of bias changed both the reactance and resistence of the crystal sufficiently to move the lower band edge a few megacycles.

From the test data, it can be concluded that a better uniformity in detection characteristics can be obtained by increasing the bias current. The manufacturer of these detector crystals recommends that a forward bias current of 50 microamperes be used to obtain best uniformity in operating characteristics while retaining a reasonable sensitivity. To obtain better uniformity in the present filter units, it is recommended that the bias current be increased to between 25 and 50 microamperes. A slight re-tuning of the seventh resonator should improve the sensitivity to a value almost as good as obtained with 20 microamperes bias.

3.0 SLAB LINE FILTER

The original filter-detector unit utilized "slab line techniques" to accomplish a filter that is near the ultimate in simplicity and compactness. The basic filter requires very few parts with the minimum number of exacting tolerances. The compactness comes from the fact that the resonators are physically shorter than a quarter wavelength. The weight of each unit including the filter and crystal mount is 1-3/4 ounces. An outline drawing of the unit appears in Figure 5 and a drawing of the internal parts of a similar type filter is shown in Figure 6.

The basic filter has the limitation that it has a perfect pass band at all odd harmonics. Although satisfactory equipment operation was achieved, the undesired harmonic responses were not as effectively eliminated as they could be with the present filter "know-how". The previous method for eliminating the third harmonic utilized a tuning circuit on two of the resonators to detune the third harmonic. This harmonic suppression technique would have been more effective if three resonators had been made anti-resonant; however, the tuning of these special circuits was so critical that no more than two were considered feasible. The higher harmonics were eliminated by the same de-tuning scheme plus the natural characteristic of the crystal detector to become a poor rectifier above 10,000 mc.

During the period since the previous filter development, a very complex RF head has been designed which contained 12 slab line type band pass filters in the receiver, 12 in the transmitter, and 18 in the local oscillator system. It also contained 24 band reject filters, several directional couplers, and many crystal mixers in printed sandwich lines. Due to the complexity and scope of this design effort, a great deal of engineering "know-how" was attained in addition to the computation of a more complete set of design characteristics for slab line filters.

3.1 Possible Improvements In Slab Line Filter

The slab line filter requires two basic improvements in the operating characteristics: (1) a more consistant response in the pass band and (2) a better suppression of undesired harmonics. Both improvements can be made by simply using a method of harmonic suppression which does not introduce critical tuning adjustments into the bandpass filter.

3.1.1 Low Pass Filter

One method of suppressing the undesired harmonics is to add a low pass filter of the type shown in Figure 7. This type of filter uses transmission lines to form a lumped parameter low pass filter. Unfortunately, this filter does not behave as a low pass filter at the higher microwave frequencies; hence, it can have spurious responses. If the filter shown in Figure 7 is designed with the high characteristic impedance sections being a quarter wavelength long at the third harmonic, the third harmonic will certainly be suppressed. If two of the low characteristic impedance sections are a quarter wavelength long at the fifth harmonic and two at the seventh harmonic, the fifth and seventh harmonics will also be suppressed. Hence, the "low pass" filter must be designed to assure that its reject bands include the frequencies that are to be suppressed. The low pass filter does have several disadvantages. First, the additional filter sections increase the length of the unit by 1-½ inches and the weight by approximately one ounce. Second, the low pass filter has extremely difficult manufacturing and assembling tolerances.

3.1.2 Coaxial Band Rejection Filter

The coaxial band rejection filter of Figure 8 could be used to eliminate the third harmonic and de-tuning techniques to eliminate the higher harmonics. This de-tuning will be less critical than when used for elimination of the third harmonic.

3.1.3 Slab-Line Band Rejection Filter

Since the low pass filter has several pass and reject bands at the microwave frequencies, band rejection techniques will give equally good results. One type of strip-line band rejection filter has been proposed by E.M.T. Jones and J. T. Bolljahn[1] is shown in Figure 9 as modified for slab line techniques. The design equations differ from those of the reference in that modern filter theory should be used.

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[1] "Coupled-Strip Transmission Filters And Directional Couplers", E. M. T. Jones and J. T. Bolljahn, Page 79,- 81, IRE Transactions on Microwave Theory and Techniques, Volume MTT-4, No. 2, April 1956.

3.1.4 Harmonic Decoupling Technique For Slab-Line Filter

Another band rejection scheme that is particularaly applicable to this problem has been used in coupled strip transmission line filters for elimination of even harmonics. The coupling between resonators is in the form of a quarter wavelength directional coupler. At all even harmonics, the voltage coupling coefficients of the directional couplers are zero, effectively eliminating these harmonics. With such a filter, the odd harmonic response is still present.

In the slab line filter, the resonators are anti-resonant at the even harmonics; hence, some of the odd harmonics can be eliminated by making the directional coupler between resonators an even number of quarter wavelengths long at the undesired harmonic frequency. In the original filter units, the resonators have a physical length of 60 degrees to the fundamental and 180 degrees to the third harmonic; however, the capacitive tuning screws give the resonators electrical lengths of 90 degrees and 270 degrees respectively. The electrical length of the directional coupler is effectively 90 degrees because the capacity is not contained within the center conductor. If a hole is drilled into the tips of each of the resonator post in such a manner that the tuning screw does not contact the sides of the hole, the effective electrical length of the directional coupler is reduced to the required length for suppression of a particular harmonic. If the characteristic impedance of the transmission line comprised of the hole and tuning screw is properly selected, the third harmonic will be effectively eliminated and the tuning adjustments will no longer be critical. It should be possible to design the seven resonators such that four eliminate the third harmonic and three eliminate the fifth harmonic as shown in Figure 10.

3.1.5 Recommended Method of Harmonic Suppression

The harmonic decoupling technique should be given primary consideration because it requires a minimum of modification with no increase in the filter size.

If the harmonic rejection is insufficient, the addition of a band rejection filter section will improve the rejection with a minimum increase in size or weight.

3.2 Impedance Match Of The Detector Crystal

The filter is used as a broad bandwidth impedance matching transformer for the crystal. For this reason, the crystal mount is made an integral part of the filter. A perfect impedance match to the crystal could not be achieved with 20 microamperes bias because the crystal and mount behaved as a multiple tuned circuit with a "Q" value that was too high. A higher bias current is known to reduce the "Q" of a detector crystal; hence, a better impedance match can be expected if the filter is re-designed for a higher bias current.

4.0 PRINTED MICROWAVE BANDPASS FILTER

Considerable interest has been expressed in the possibility of designing the microwave filter to tutilize printed circuit techniques. During the design of the previous filter unit, printed circuit filters were included in the preliminary investigation, but rejected because of the required form factor of the filter. This section will deal with the design of a printed bandpass filter.

4.1 Types Of Printed Microwave Transmission Lines

Three types of printed microwave transmission lines, microstrip, sandwich line, and air dielectric strip line, are illustrated in Figure 11. Of these three lines, sandwich line is the most adaptable to the requirements of the filter because of its basic ruggedness. The microstrip line cannot be used because of its extremely high radiation loss when resonated. Air dielectric strip line is not recommended because of the size and weight of the supporting structure.

4.2 Coupled Transmission Line Filter

Of the various types of transmission line filters, the coupled transmission line filter appears to be best for the application because the manufacturing tolerances are much less severe than those associated with the filter types containing series capacity coupling between resonators. The reproducibility of the filters is better than is obtainable from other types of printed microwave filters.

The coupled transmission line filter is represented in Figure 12. The strip conductors are shown, but the top of the ground plane and dielectrics are omitted for simplification. The description of this type of printed microwave filter was first published by Jones and Bolljahn.[1] Later, an improved theory for the bandpass case was published by S. B. Cohn [2]. Although this theory is quite accurate, some cut and try is required before the filter design is acceptable since there is no way to tune each resonator after assembly. Tuning is accomplished by changing resonator dimensions on a new photographic negative by optical projection techniques.

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[2] "Parallel Coupled Transmission Line Resonator Filters" S.B. Cohn, IRE Transactions on Microwave Theory and Techniques, Vol. MTT-6, April 1958, Pages 223-231.

4.3 Spurious Resonances Of The Sandwich Line Filter

The sandwich line filter contains half wavelength resonators which, like a slab line filter, will resonate at all harmonics. The even harmonics are suppressed in the coupling between resonators because the coupling coefficient is zero at the frequencies where the electrical length of the coupling region is even multiples of 90 degrees. The odd harmonics are not suppressed and have a bandwidth comparable to the fundamental frequency.

The odd harmonic outputs can be eliminated with band rejection filters tuned to the third and fifth harmonics. Higher frequency harmonics are eliminated by the tremendous reduction of the crystal detection efficiency.

4.4 Detector Crystal For Sandwich Line Filter

The ordinary cartridge type crystal cannot be used with the sandwich line filter because the associated crystal mount makes the over-all unit too large for normal packaging considerations. A new series of microminiature crystals have been introduced by Sylvania which are almost as small as the tip of a cartridge type crystal. These microminiature crystals come with attached leads for soldering into printed microwave systems. The 1N833 detector crystal is rated by the manufacturer to have tangential sensitivity of -40 dbm. The rating is based on a 10 mc bandwidth with zero dc bias current. If the crystal is operated with an applied forward bias current and the video bandwidth is reduced to 2 mc, the sensitivity would be improved approximately 10 db. The maximum sensitivity attainable from the 1N833 crystal at its present state of development is not as good as the MA 4088 crystal.

4.5 Anticipated Sensitivity Of Printed RF Head

The sensitivity of the printed filter is expected to be approximately -45 dbm when the loss in the cables from the antennas and the increased filter losses are considered. The computed filter insertion loss is approximately 2.5 db.

4.6 Fabrication Problems In Printed Sandwich Line Filters

Printed filters are fabricated from copper laminated dielectric sheets consisting of a dielectric sheet sandwiched between the copper foil bonded to each surface. One method of fabrication is to photo-etch the circuit from the copper on one dielectric to form the conducting strip similar to the microstrip of Figure 11. A second dielectric sheet with foil on only the top side is placed on the etched sheet to form the sandwich line of Figure 11. The assembly is riveted together. This type of fabrication has one problem which hinders exact reproducibility. The dielectrics tend to warp slightly, leaving a small gap between the strip and the unbonded dielectric. This gap allows a parallel plate waveguide mode to be excited which results in spurious filter responses. Closely spaced rivets will eliminate the waveguide mode and also reduce the gap.

A second method of fabrication completely eliminates the effects of the air gaps. Here, the printed circuit is etched on both dielectric laminates so that each looks like the microstrip of Figure 11. The printed circuitry on one dielectric must be the mirror image of the other. These "microstrips" are sandwiched together to form the sandwich line circuit. Now, the air gaps due to warping have practically no effect on the circuit. Although this is a solution to the air gap problem, it presents an even greater problem by requiring perfect alignment of the two halves of the sandwich. This second method of fabrication is not recommended for this filter because it would be impractical to try to achieve the required accuracy of alignment.

There are other difficulties which are not controllable by the fabricator of the filters. First, the thickness of the dielectric laminates available is not within low percentage of error realized in the photo-etched conducting strips; furthermore, the thickness varies slightly from point to point on the dielectric sheet. Second, whenever a fiberglass filled dielectric is used, the non-uniformity in dielectric constant from point to point in the dielectric makes the filter characteristics somewhat unpredictable.

The filter could be fabricated from copper laminated pure teflon with a fairly good probability of success. However, it is not anticipated that the uniformity would be any better than obtained from the slab line filters because of the non-uniformity associated with most detector crystals.

5.0 CONCLUSIONS AND RECOMMENDATIONS

It is recommended that the slab line filter be re-designed slightly for any future systems. It was explained that the tuning of the filter would be less critical if a different type of harmonic suppression were used. A 50 microampere forward bias current would improve uniformity among the detector crystals. A mechanical improvement in the cap of the crystal mount is desirable also. This re-design is at most, the correction of the deficiencies that became app[redacted]with the experience gained from the previous d[illegible]ment.

The possibility of using a printed microwave filter has been again considered. Previously, it was rejected because it could not be packaged with the required form factor. In the future, a different location for the R.F. head may be possible; hence, this type of construction has been considered in greater detail. Computations indicated that a compact printed microwave filter will have poorer sensitivity than a slab line filter. Since the variation of the crystal characteristics is the major contributor to pass band variation, the printed filter would have no greater uniformity of passband characteristics than can be achieved with the present knowledge of slab line filter techniques.

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NRL Filter
Crystal Spread
Zero Bias

Filter S/N 47

Note: 20db points used in plotting this graph are not shown.

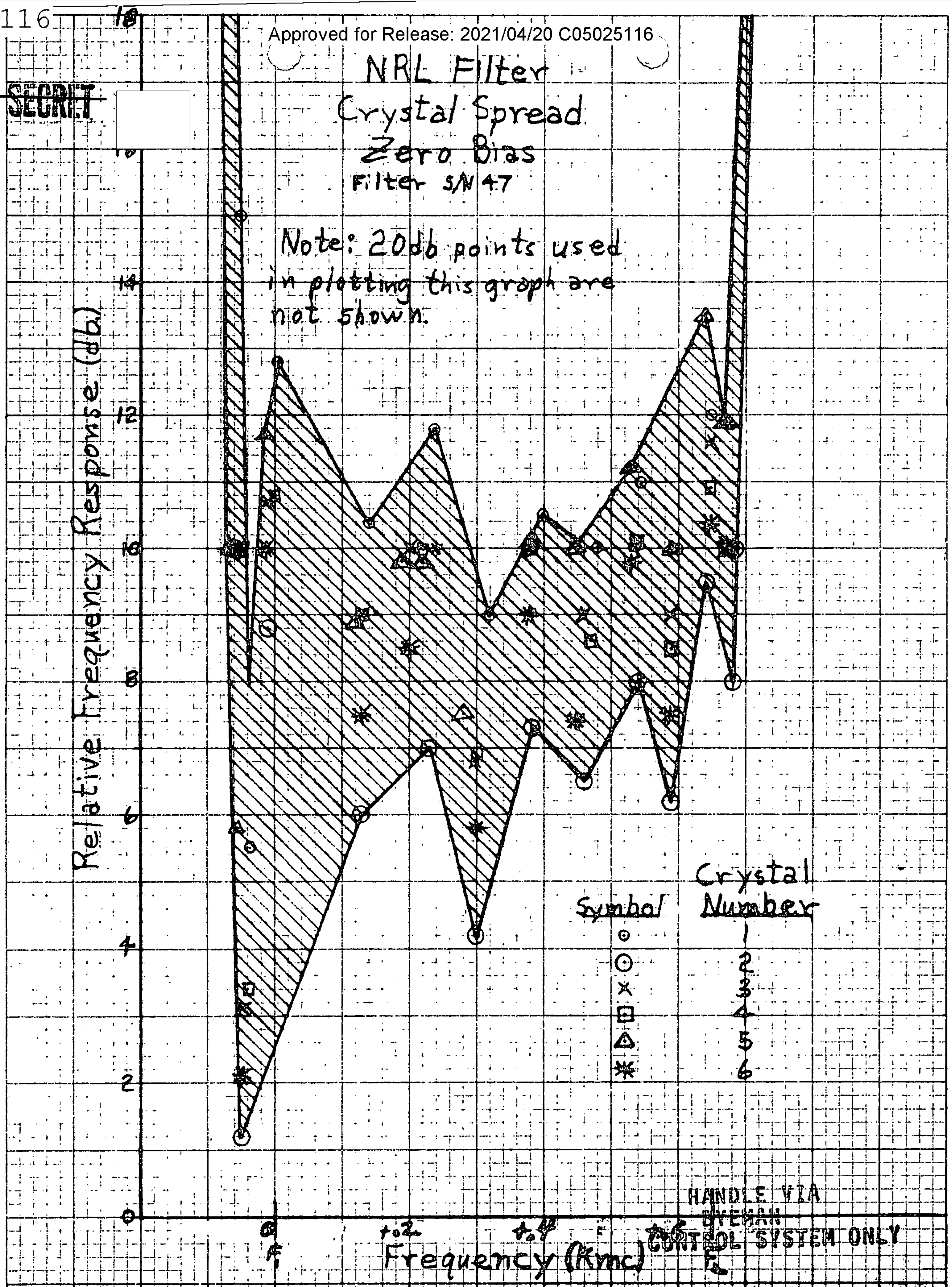

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Figure 1

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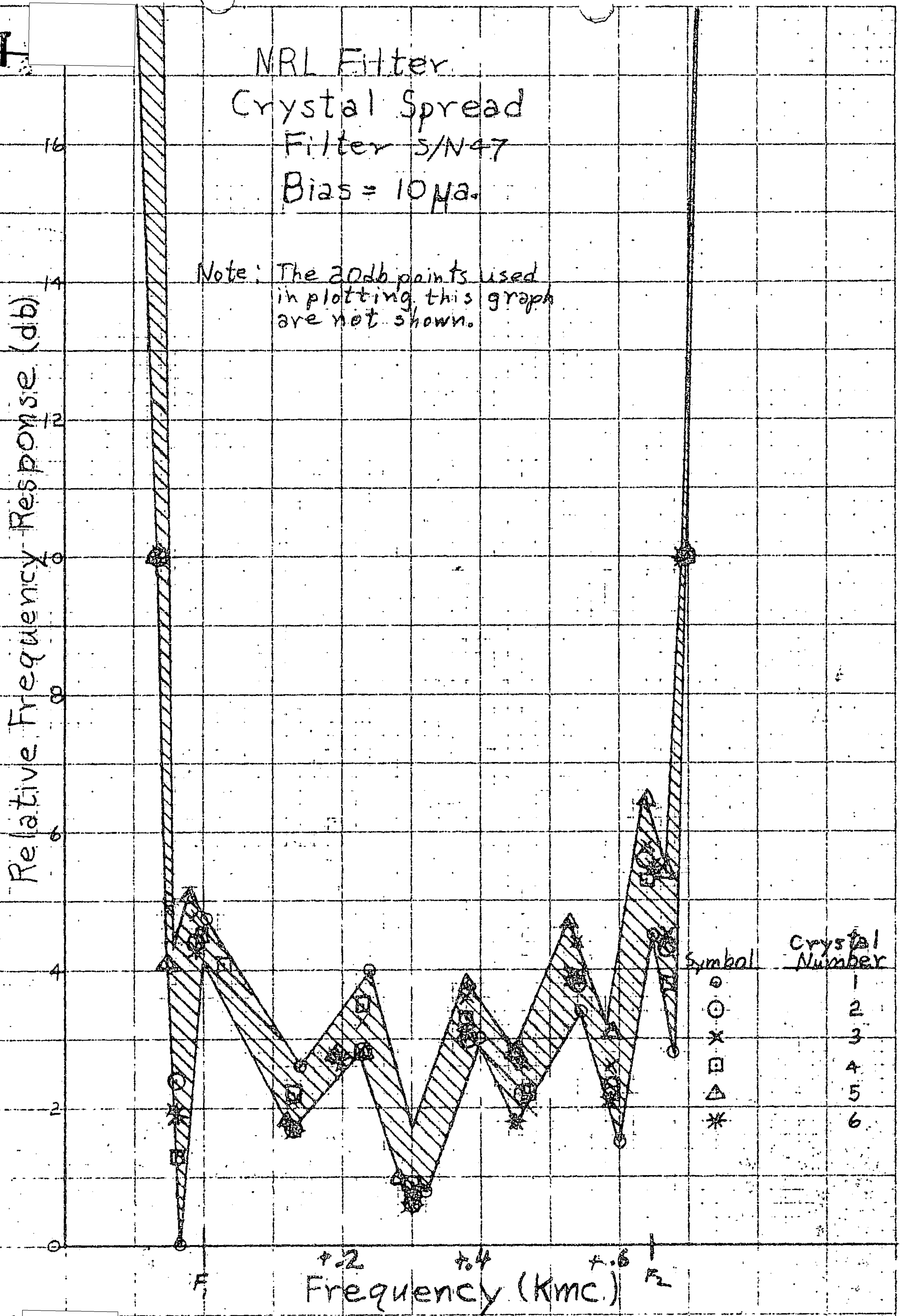

FIGURE 2

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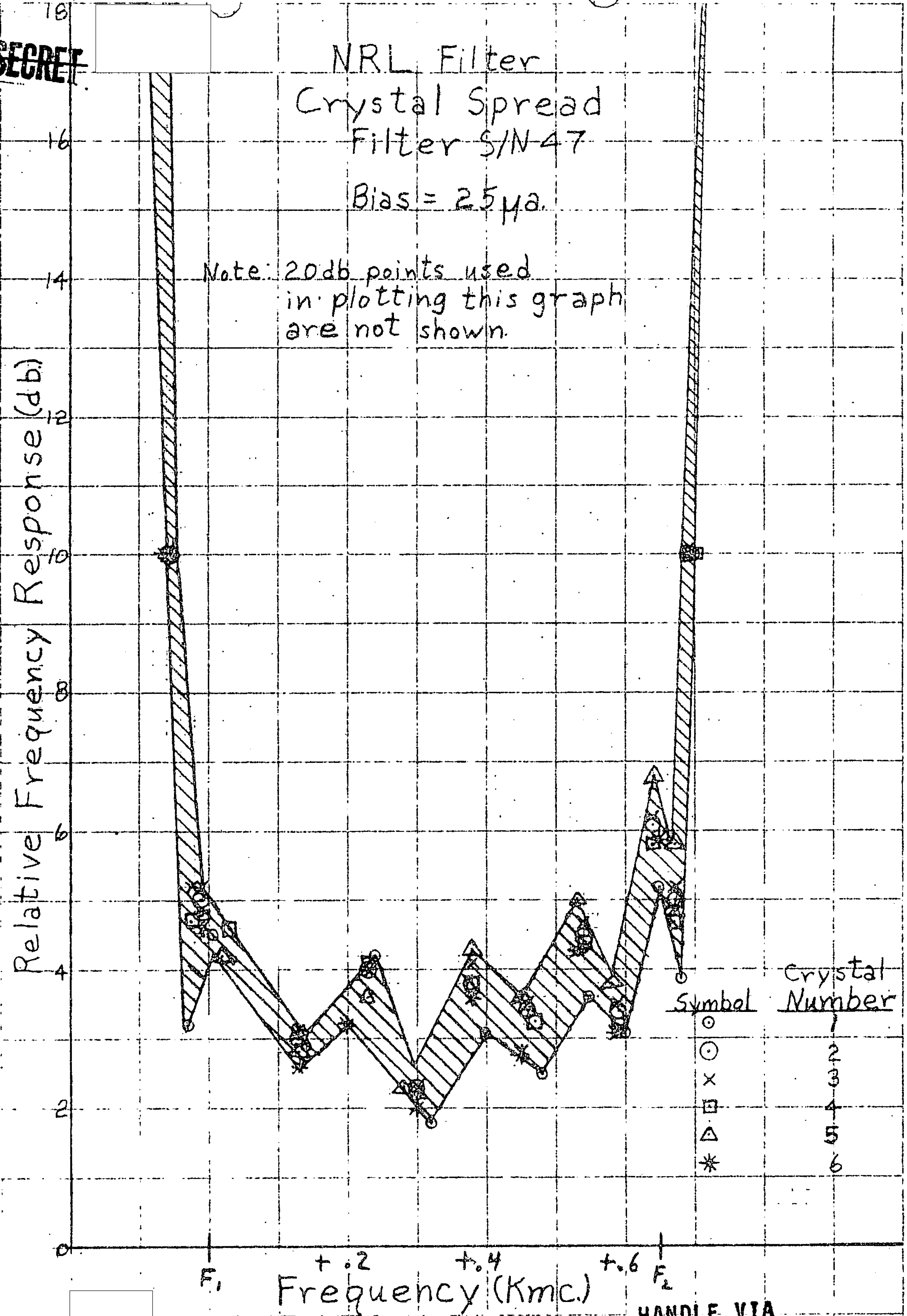

FIGURE 3

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R Muesel, KSS, 30 Oct 1960

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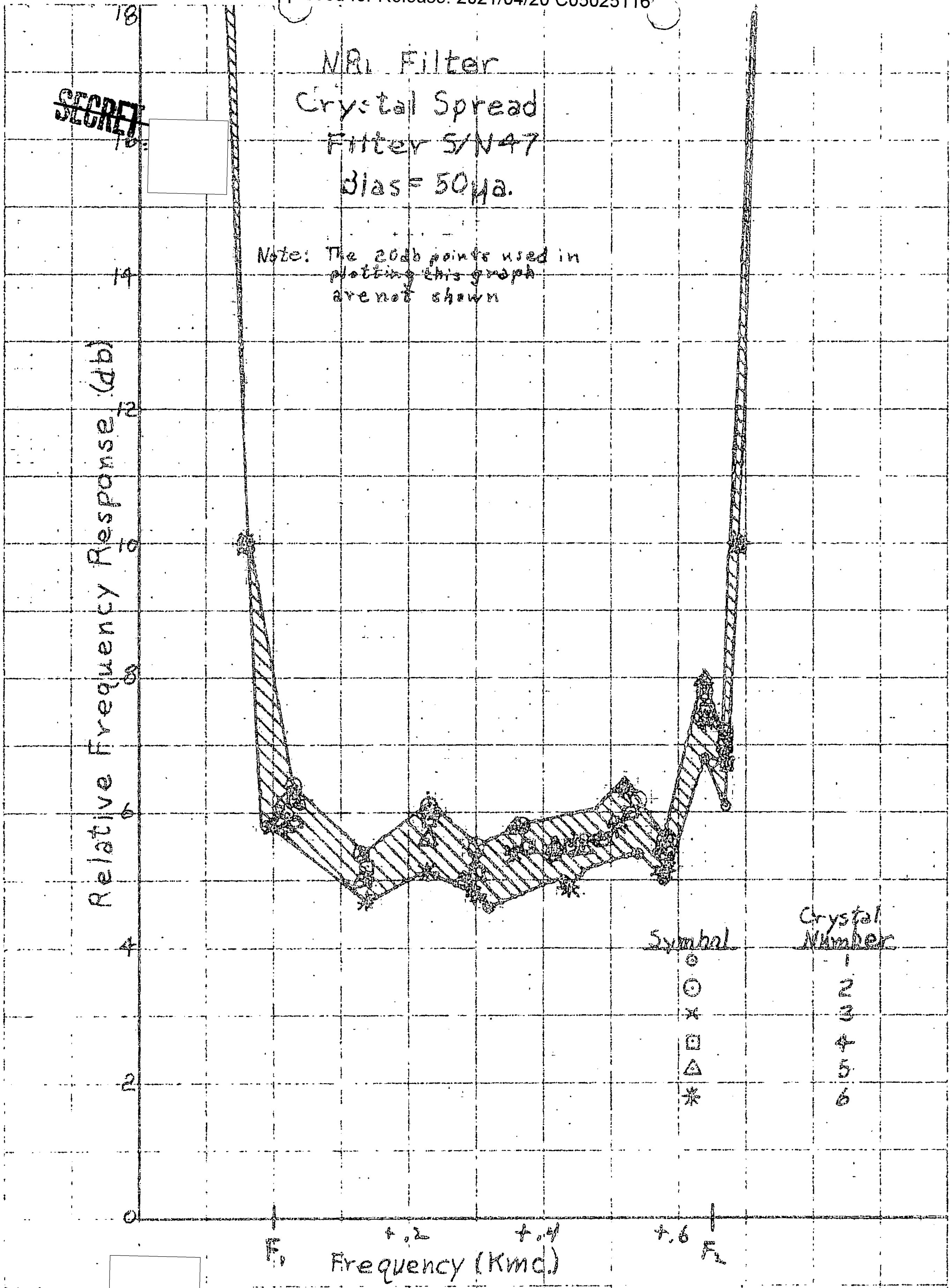

NRL Filter
Crystal Spread
Filter S/N47
Bias = 50 μa.

Note: The 20db points used in plotting this graph are not shown

Figure 4

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KSS, 4 Oct 60

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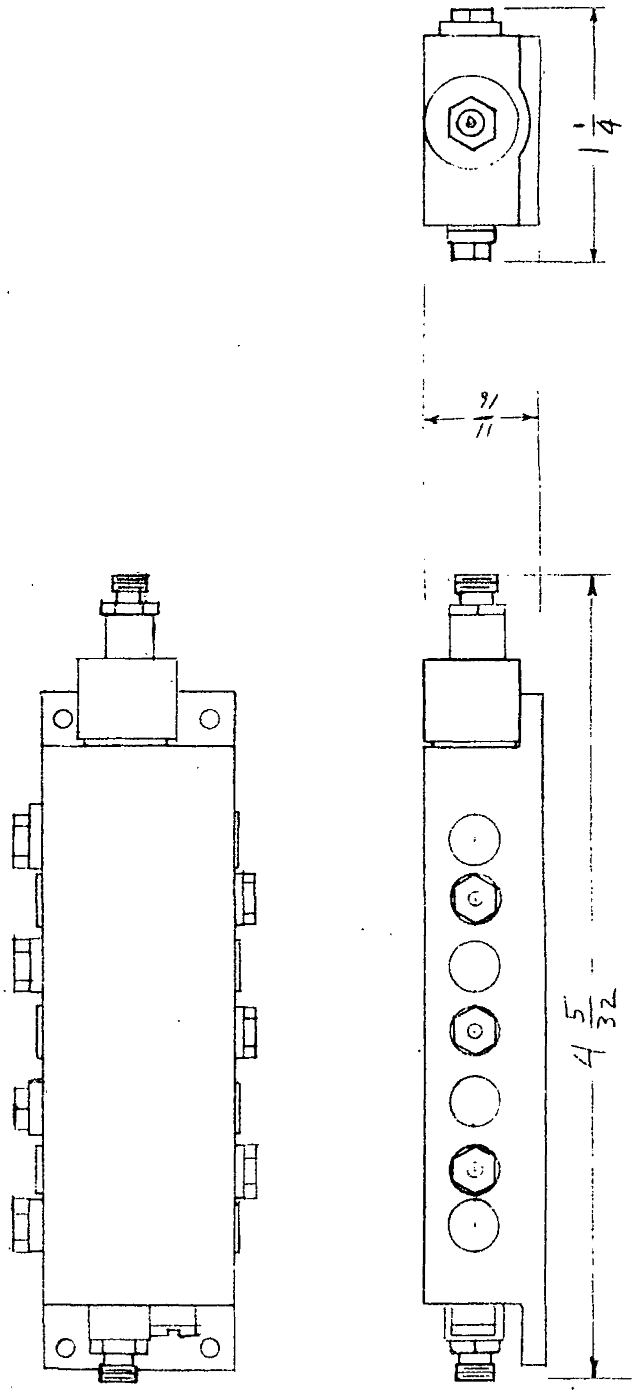

RF HEAD

FIGURE 5

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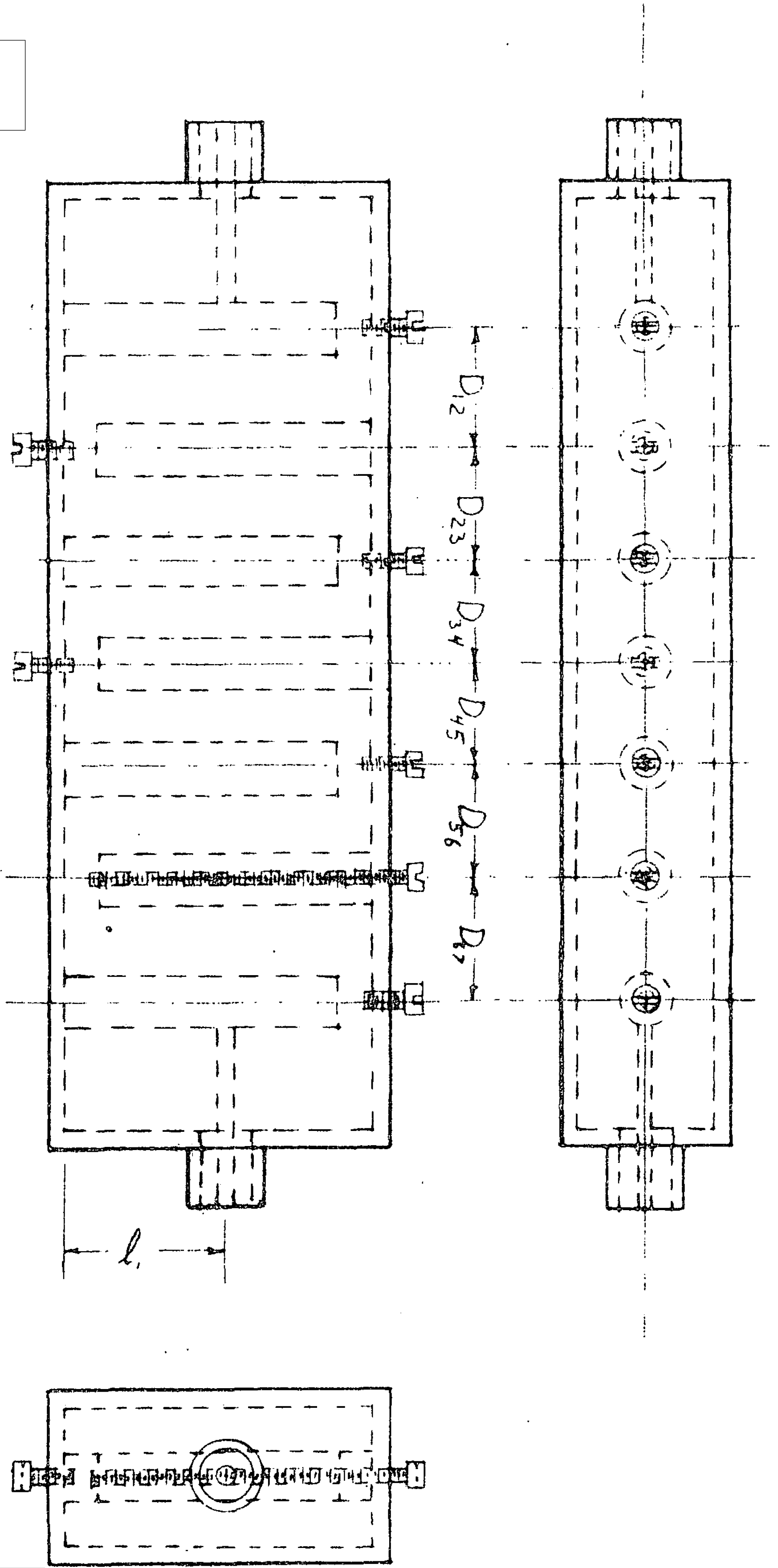
Fig 6

NEW TYPE FILTER



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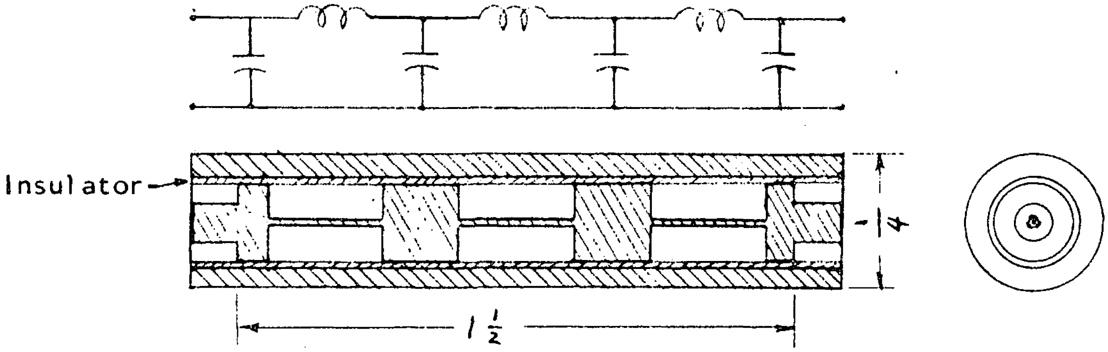

FIGURE 7

Low Pass Filter And Equivalent Circuit

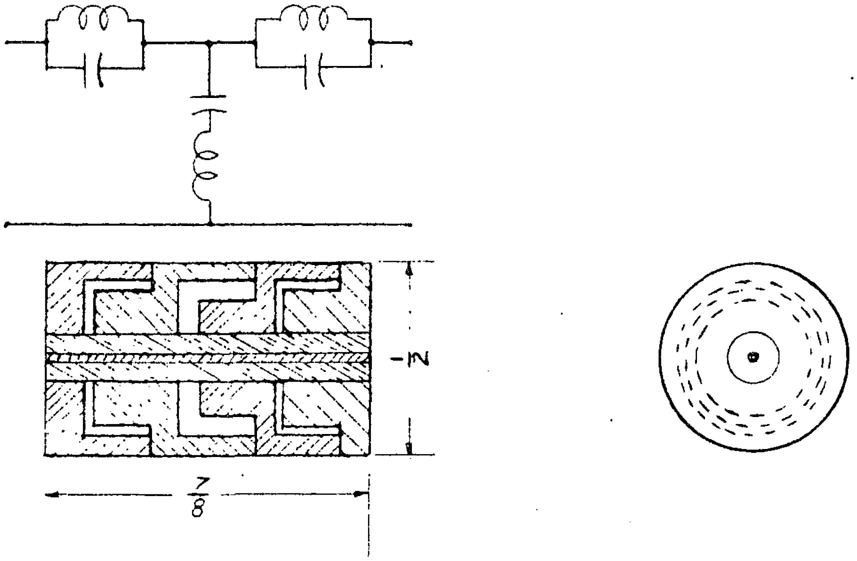

FIGURE 8

Band Reject Filter And
Equivalent Circuit at Reject Frequency

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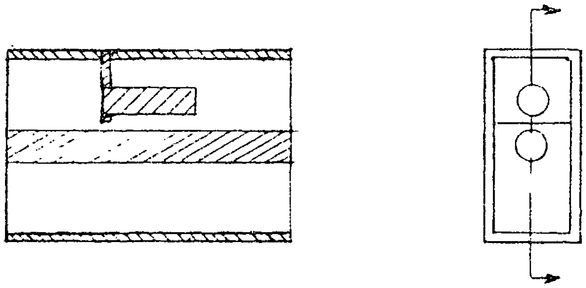
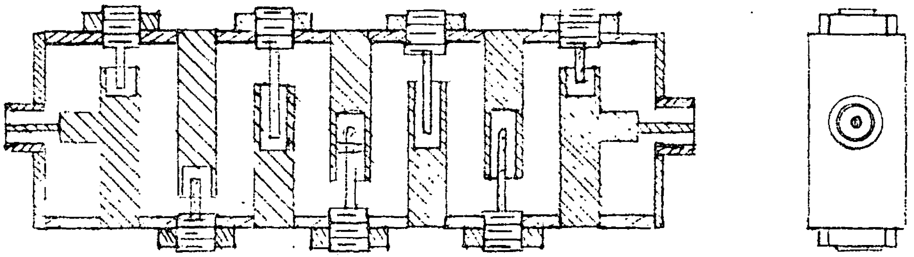


SLAB LINE BAND REJECTION FILTER

FIGURE 9



SEVEN RESONATOR FILTER WITH DECOUPLING OF
THIRD AND FIFTH HARMONICS

FIGURE 10

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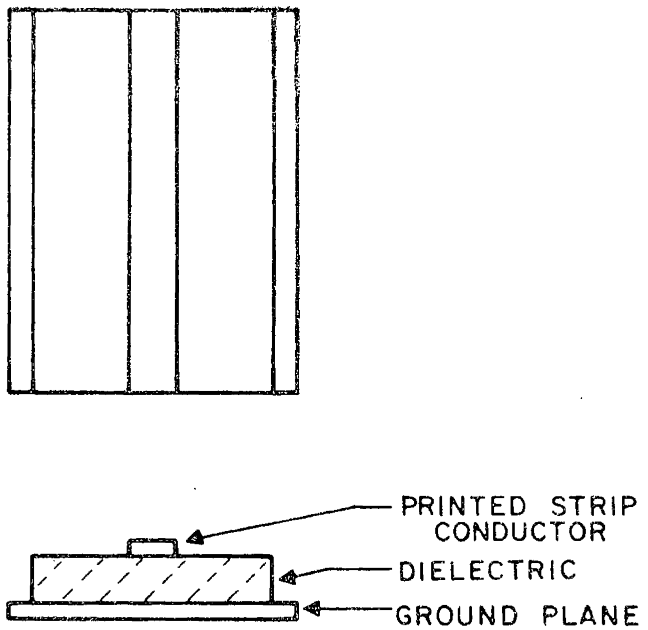
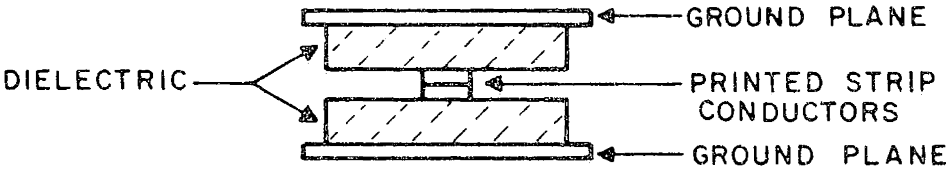
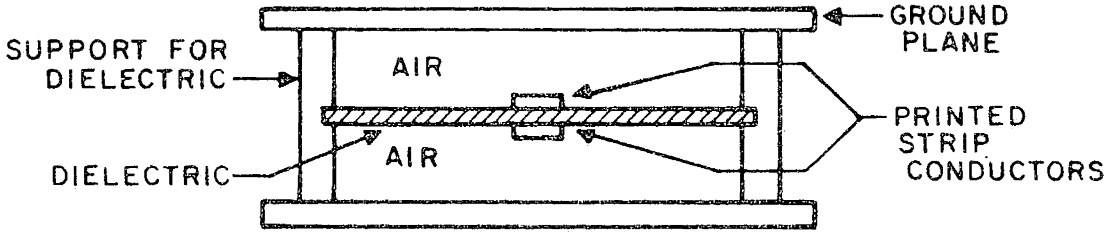


MICROSTRIP



SANDWICH LINE



AIR DIELECTRIC STRIP-LINE

PRINTED MICROWAVE TRANSMISSION LINES

FIGURE 11

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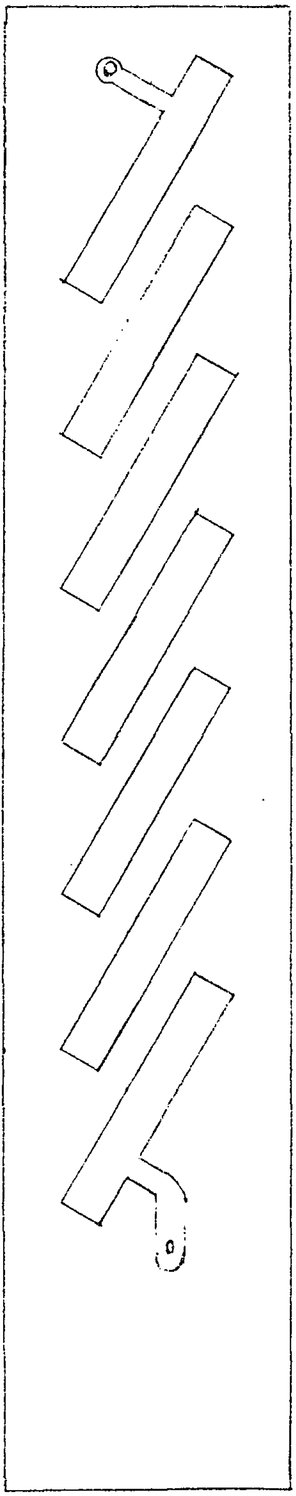

COUPLED TRANSMISSION LINE FILTER

IN SANDWICH LINE

FIGURE 12

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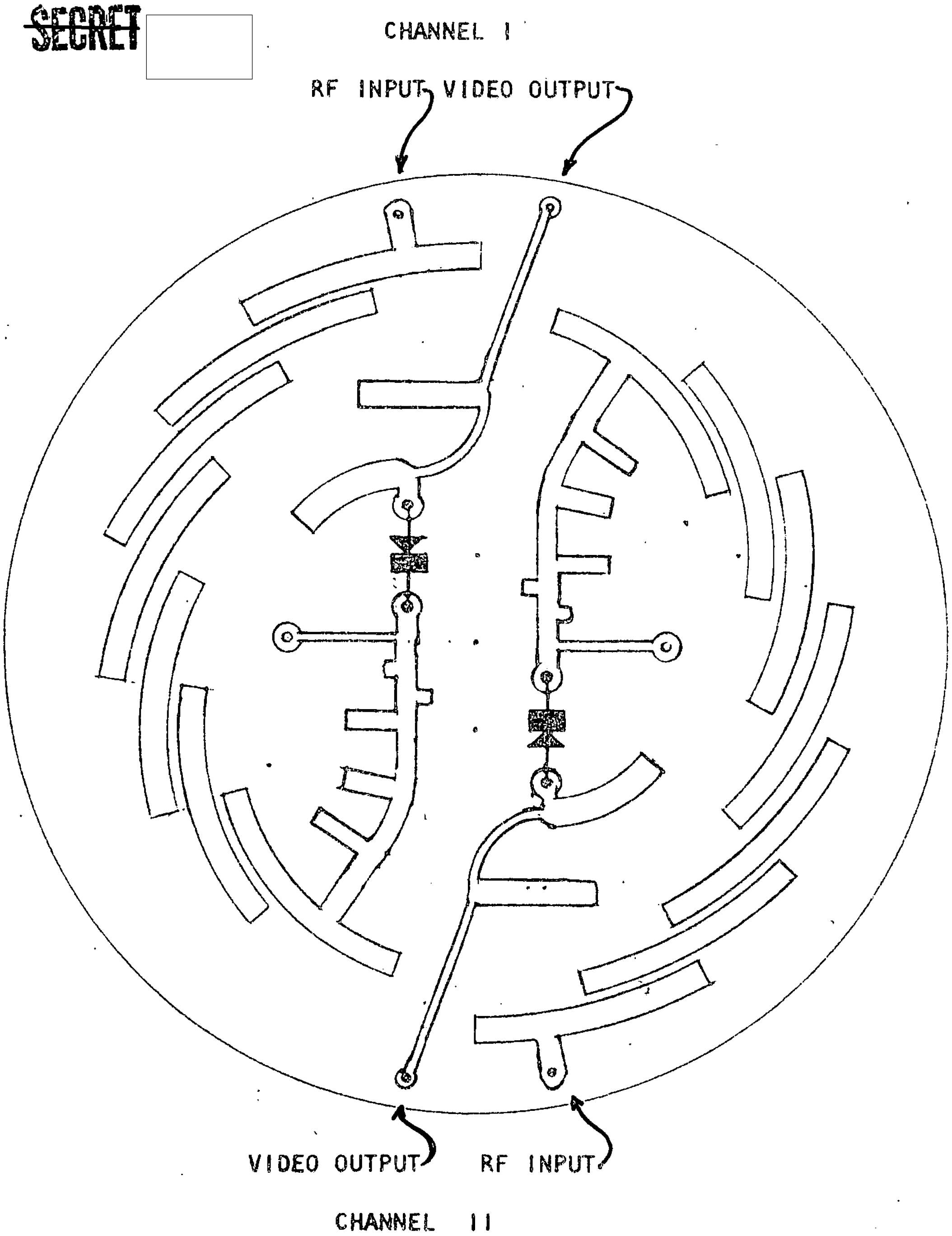

POSSIBLE LAYOUT OF TWO CHANNEL SANDWICH-LINE RF HEAD

FIGURE 13

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