CRYSTAL CHECKER FOR BALANCED MIXERS

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To achieve optimum performance from a microwave receiver that uses a balanced crystal mixer, matched pairs of crystals should be used. However, depending on the reason for choosing the balanced mixer for a particular receiver, the crystal characteristics that should be matched and the degree of balance that is required vary considerably. The three principal reasons for using balanced mixers are:

1. To minimize noise figure by suppressing local-oscillator noise.

2. To suppress local-oscillator power radiation.

3. To reduce receiver sensitivity to certain spurious responses.

For radar receivers, the first reason is the only important one, and fortunately it places the least stringent requirement on the degree of balance.

D-C Test Set

A d-c crystal checker of special design[1] can be used to match pairs of crystals for local-oscillator noise suppression and to predict receiver noise figure. To suppress local-oscillator noise, conversion loss and i-f resistance must be matched. To suppress local-oscillator power radiation and spurious responses, r-f impedances must be matched. There is only a limited requirement on r-f impedance matching for noise suppression because unbalance from this source results from differences in the change in electrical lengths of the two crystals from the local-oscillator frequency to the signal frequency. Crystals in most holders do not represent a high-Q circuit, and signal and local-oscillator frequencies are usually separated by only a few per cent. It therefore follows that changes in electrical lengths for two crystals of the same type construction will be nearly equal, even though the magnitude of their electrical lengths may be different.

Description of Test Set

The manner in which the TEST reading of the d-c crystal checker indicates the nonlinearity of crystals and the manner in which this nonlinearity is related to conversion loss has been described[2], but a brief description will be included here for completeness.

The tests made by the crystal checker determine the nonlinearity of the forward portion of the E-I curve of the crystal, the relative forward resistance, and the relative back conductance. The forward nonlinearity determines the low frequency conversion loss, which is directly proportional to microwave conversion loss if the crystal is properly coupled to its microwave circuit[3]. For crystals of equal conversion loss, the relative forward resistance is proportional to the i-f resistance of the crystal. The relative back conductance determines the amount of current that will flow, at a particular excitation level, through the noise-producing back resistance. Relative back conductance is therefore a sensitive indicator of relative excess noise temperature. Relative back conductance also affects conversion loss, but for crystal checking purposes this effect can be ignored.

Forward nonlinearity is measured by a two-point d-c incremental method in the following manner. By adjusting a potentiometer, an initial, or CAL, reading is established such that a reading of approximately mid-scale would be obtained in the TEST position of the CAL-TEST switch if the crystal were linear. This CAL reading is related to relative i-f resistance in such a way that high CAL readings correspond to low i-f resistance, and vice versa. The CAL-TEST switch is then set to the TEST position, causing a fixed voltage increment to be subtracted from the voltage that establishes the CAL reading. The current reading at this point, the TEST reading, is an indication of nonlinearity. The lower the current reading, the lower the conversion loss will be. To measure relative back conductance the NORM-REV switch should be reversed from the position for forward readings. The current reading in this position, with the CAL-TEST switch still in the TEST position, will indicate relative back conductance. The voltage in this case is equal in magnitude to that for the forward TEST position.

Figure 1 shows calibration curves of conversion loss, noise temperature and noise figure for forward TEST readings and the modification in noise temperature and noise figure that results from excessive relative back conductance. For undamaged crystals the relative back conductance is usually negligibly small; therefore, the reverse TEST reading is not used in matching crystal pairs. It is not logical to give a universal calibration curve of i-f resistance versus CAL reading because of the strong dependence on such things as mixer configuration, local-oscillator drive, and radio frequency. For instance, nominal i-f resistance can vary by about 3 to 1 as a function of mixer configuration. This variability is in addition to that resulting from variations in applied local-oscillator power.

Matching Procedure

Using the CAL and forward TEST readings, the following procedure can be used to choose matched crystal pairs:

1. Record CAL and TEST readings of a group of crystals.

2. Pair crystals that have equal CAL readings, within half a scale unit, and equal TEST readings, within half a scale unit.

3. If matching within half a scale unit is not possible, differences should be in the same direction and of about the same magnitude.

For instance, a crystal with CAL-TEST readings of 63-24 should be paired with one having readings of 62-25 rather than with one having readings of 65-23. It is not recommended that crystals with differences larger than two CAL units and/or one TEST unit be paired if adequate noise suppression is to be achieved.

Experimental Results

Tests on S-band and X-band receivers show that, whenever the readings are within the recommended half-unit limits, sufficient noise suppression is obtained to assure correlation between TEST readings and receiver noise figure to the same accuracy as is obtained for unbalanced mixers. The use of a d-c tester to match crystals for operation above 10 Kmc is not recommended because of the severe reactive effects found at these frequencies.

The relation between noise figure and TEST readings for a typical receiver using pairs matched by the checker is shown in Figure 2. It is seen that the correlation is good.

If CAL and TEST readings are not well matched, a significant increase in noise figure may occur as a result of the presence of excess local-oscillator noise. For instance, in Figure 3 noise figure distributions are shown for 48 randomly paired 1N21C crystals at 3 Kmc. The distribution at the bottom of the figure applies to 19 of the 48 pairs that were found to be adequately matched by the crystal checker. It is seen that the maximum noise figure is reduced by about 1 db and the average is reduced by about 1/2 db when the crystal checker is used. At 9.3 Kmc measurements of noise suppression were made directly on 33 pairs of 1N23B crystals. The distribution of suppression for random pairing is shown in the upper histogram of Figure 4. The lower histogram shows the improvement obtained by using the crystal checker. The minimum suppression is increased by about 5 db and the average is increased by about 10 db.

Noise Suppression Requirements

Theoretical Considerations

In addition to the experimental findings a calculation was made to analyze the effects of unbalance in conversion loss or i-f resistance on noise suppression. Each characteristic was considered separately with all other characteristics balanced. The results of the calculations are shown in Figure 5. If unbalance occurs in both conversion loss and i-f resistance, the noise suppression can be greater or slightly less than that shown for the individual characteristics.

Noise Characteristics of Local Oscillators

To determine the amount of noise suppression that is required for particular receivers, a brief search of the literature was made to determine the noise characteristics of local oscillators. Figure 6 shows the excess noise (t-1, where t is noise temperature in power units) contributions at 30 mc from three typical klystron local oscillators[4]. The curves marked "Hi" and "Lo" apply respectively to operation at the high-frequency and the low-frequency half-power points of the recommended high-voltage mode. The curve marked "Center" applies to the maximum-power point of the mode. Figure 7 shows excess noise as a function of intermediate frequency.

Figures 6 and 7 indicate that excess local-oscillator noise is approximately constant as a function of the ratio of radio to intermediate frequencies. They also show that, for a 9.3-kmc receiver with a 30-mc intermediate frequency, a noise suppression of 20 db is adequate to reduce excess noise to 0.1 at the high-frequency half-power point, 13 db being adequate at the center of the mode. Because most crystals have an excess noise at 30 mc that is several times this value, the effect of 0.1 unit of excess local-oscillator noise on receiver noise figure will be negligible.

If lower intermediate frequencies were used, it would seem from Figure 7 that the local-oscillator noise suppression would need to be increased. Such would be the case except that excess crystal noise, which cannot be suppressed, increases with decreasing intermediate frequency at about the same rate as does the excess local-oscillator noise.[5] Therefore, the suppression determined from Figure 6 to suppress excess local-oscillator noise to 0.1 will be about equal to the suppression required at lower intermediate frequencies to suppress excess local-oscillator noise to a magnitude significantly smaller than excess crystal noise.

Conclusions

Predictable, improved performance can be obtained in many microwave receivers by using a d-c test set to match pairs of crystals and to choose crystals for low noise figure.

The d-c crystal checker, which tests crystals with sufficient accuracy for most applications, should prove valuable to both engineers and service technicians. Its use in matching crystal pairs should materially reduce the cost of such pairs, especially because, in factory-matched pairs, parameters that do not affect local-oscillator noise suppression are matched in addition to the necessary parameters.

References

1. AIL Type 390A-3 Microwave Crystal Test Set.

2. P. D. Strum, "Mixer Crystal Checker," Electronics, Vol. 23, pp 94-97, Dec. 1950.

3. P. D. Strum, "Some Aspects of Mixer Crystal Performance," Proc. I.R.E., Vol. 41, pp 875-889, July 1953.

4. Data for the 723A/B and the 2K33 were obtained from R. V. Pound, "Microwave Mixers," Vol. 15, Rad. Lab. Series, McGraw-Hill, 1948, pp 237-243. Data for the 6BM6 were obtained from measurements at Airborne Instruments Laboratory, Inc.

5. For a discussion of this phenomenon see Reference 3.

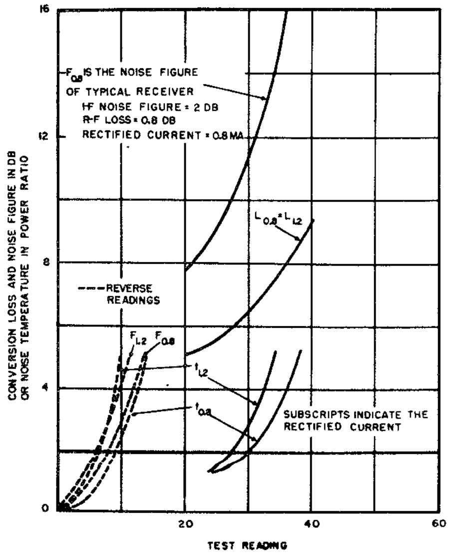

Fig. 1 - Calibration curves.

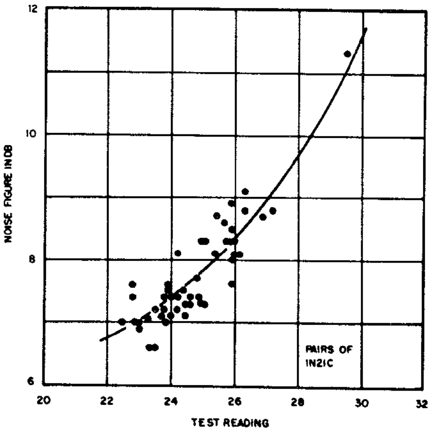

Fig. 2 - Noise figure versus test reading for a typical receiver.

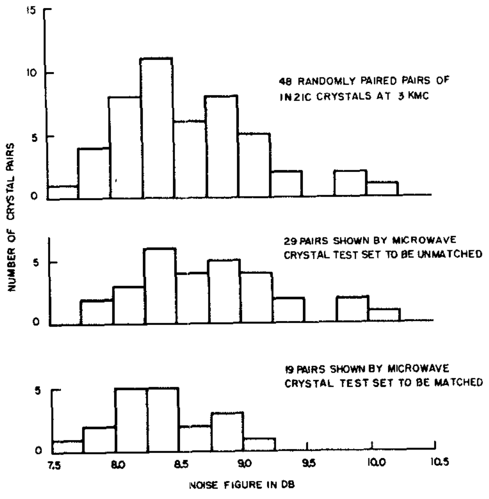

Fig. 3 - Noise figure grouping for pairs of 1N21C crystals.

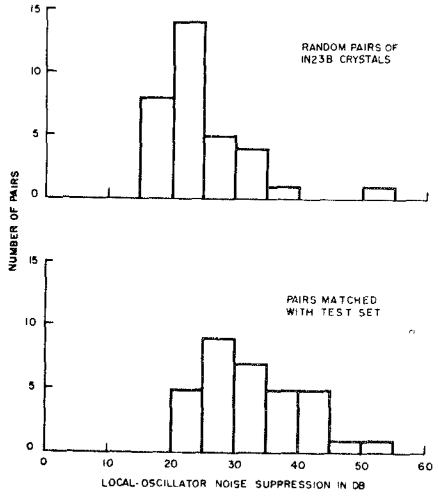

Fig. 4 - Experimental suppression of noise from local oscillator.

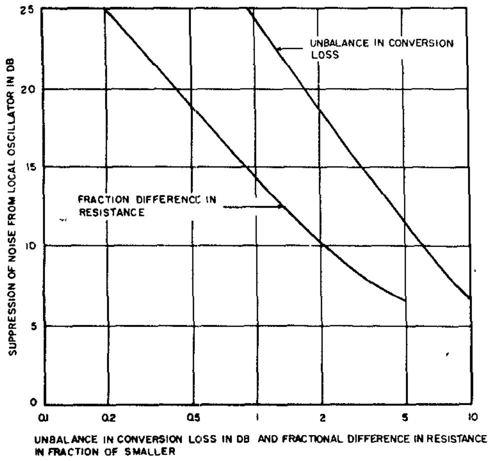

Fig. 5 - Theoretical suppression of noise from local oscillator.

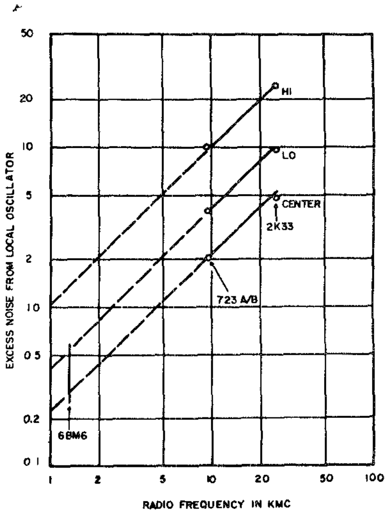

Fig. 6 - 30-mc excess noise of typical klystrons.

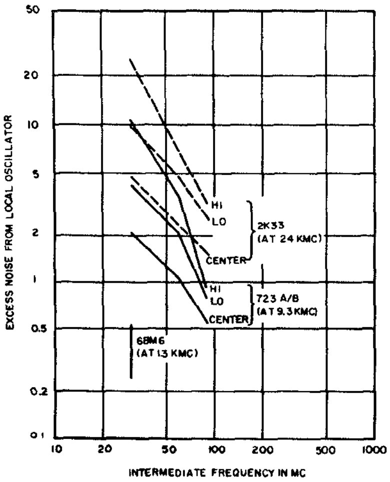

Fig. 7 - Excess noise versus intermediate frequency.