A BROADBAND MICROSTRIP CRYSTAL MIXER WITH INTEGRAL DC RETURN

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The recent introduction of practical oscillators, such as carcinotrons and backward wave traveling wave tubes, has resulted in a need for broadband mixers. The combination of the broadband mixer and local oscillator results in the realization of a microwave receiver, capable of covering a two to one frequency range. Tuning can be accomplished in microseconds by changing the voltage applied to one of the electrodes of the oscillator. This broadband mixer and local oscillator combination has a number of practical uses in novel airborne electronic systems, remote tuning receivers, spectrum analyzers, and automatic antenna pattern receivers.

Narrow band mixers which are usually used in radar sets are designed to operate at a single frequency and can be fixed tuned for optimum performance at the particular frequency of the radar. In a broadband mixer, however, such tuning is not possible, so that precautions must be taken to keep the input VSWR of the mixer low at all frequencies of interest.

Local oscillator coupling in a single frequency mixer is usually accomplished by loops or capacitive probes. In either case, tuning is used to correct the mismatch seen by the local oscillator. When the local oscillator in a broadband mixer sees a poor match, it is likely to be pulled off frequency; but more important, if the match varies with frequency, the local oscillator power incident on the crystal will also vary with frequency. This in turn influences the r-f impedance at the input. In general, the r-f impedance characteristic improves with increased incident local oscillator power but if the local oscillator power becomes too large, the noise temperature of the mixer will become excessive. This will then lead to a poor noise figure for the receiver and a reduction in sensitivity. An optimum noise figure results usually when the crystal current is between 0.5 and 1.5 ma. It is important therefore that the local oscillator coupling be maintained reasonably constant over the entire frequency band.

The method of local oscillator coupling to a broadband mixer utilizes a broadband coaxial directional coupler. Such couplers are built to cover an octave uniformly and offer the further advantage of loose coupling between the local oscillator and signal line, thus insuring little loss of signal energy into the local oscillator circuit.

When equipment is designed for airborne use, strict limitations are imposed on the size and weight of the components. A coaxial directional coupler is often too bulky and heavy to meet the size and weight restrictions of the particular equipment in which it is to be included. For this reason, a broadband mixer utilizing a microstrip directional coupler was developed by Sylvania's Boston Engineering Laboratory.

Two views of the mixer are shown in Fig. 1. The left hand view shows the microstrip directional coupler and indicates the positions of the local oscillator connector and the signal input connector. This view also shows the relative positions of the matched load terminating the local oscillator line and the position of the coaxial crystal holder. The directional coupler was cut from commercial microstrip stock following the design given in the Federal Telecommunications Co. microstrip manual. The coupler has a coupling of about 22 db at S-band and is uniform, within a few db, over an octave. The directivity is better than 15 db. Coupling can be varied in the design stage by varying the spacing between the local oscillator strip and the signal strip.

In order to illustrate some of the problems affecting r-f match, it might be well to investigate the equivalent circuit of a mixer which is shown in Fig. 2. The portion of the circuit inside the dotted lines shows the crystal parameters. R_S is the spreading resistance due to the bulk resistance of the semi conductor. R_B is the barrier resistance, and C_B is the barrier capacitance. C_P is the r-f by-pass capacitance introduced at the IF terminals of the mixer. It is usually about 15 uuf, but IF amplifiers with wide passbands sometimes require a lower value than this. The microstrip mixer mentioned above was required to have less than 5 uuf by-pass capacity.

Again referring to Fig. 1, the RF choke is used to complete the dc path through the crystal. In a broadband coaxial mixer this choke is usually made by stretching a thin steel wire radially between the center conductor and outer conductor of a coaxial line. The thin wire forms the center conductor of a shorted high characteristic impedance line in shunt with the main line. The use of steel makes this line lossy and alleviates somewhat the shunting effect when the length of this line is even multiples of a quarter wavelength.

Besides the weight and size reduction offered by the use of a microstrip directional coupler, a further advantage of microstrip lies in the ease with which the dc return can be made. Fig. 3 shows the cross-section of a microstrip line and the electric field configuration therein. Since over 75 per cent of the transmitted energy is confined to the dielectric, the field strength is low outside the dielectric. It was therefore decided to use a dc return in the form of a loop as indicated in Fig. 3.

The loop may be considered as a (wire above the ground plane) transmission line, shorted (rather imperfectly) at one end, and in shunt with the microstrip transmission line at the other end. The characteristic impedance of such a line is proportional to the logarithm of four times the height of the wire above the ground plane divided by the diameter of the wire. Therefore, it would seem desirable to increase the height of the loop as much as possible and to use a small diameter wire. However, another factor, that of radiation from the loop, also is a factor to be considered. The wire above the ground plane transmission line can be analyzed by methods applicable to a two wire line. An article by Dr. J. E. Storer in the November 1951 Proceedings of the IRE shows that the radiation from a two wire line is roughly proportional to the square of the separation between these lines and therefore indicates that h should be small to minimize radiation loss.

Transmission losses were measured for various loop sizes and loop positions. It was found that the losses for #26 copper wire were small providing the spacing was not large enough to permit the first resonance of the loop. Losses as high as 2 db were measured for loop spacings of one inch. The loss vs. frequency curve followed a damped resonance response with a peak at about 3500 mcps. For spacings as close as 1/4", no resonances were observed and the losses were less than .15 db over the octave band. The loss was also measured for the dc return perpendicular to the microstrip. It was found that for close spacings, the loss was unaffected by the position of the return on the strip line. For mechanical reasons the return wire was placed directly on the dielectric. The measured insertion loss of the signal input channel is shown in Fig. 4. The increased loss due to the dc return proved to be less than .1 db across the octave band. The crystal holder is connected to the microstrip by the standard coax-to-microstrip transition. The 50 ohm coaxial line holder was inductively over-cut to improve the crystal match.

Fig. 5 shows a graph of the tangential signals obtained with this mixer over the frequency range for which the mixer was designed. The measurements were obtained using an IF amplifier having an effective noise bandwidth of 10 mc. The tangential sensitivity is greater than -87 dbm over the band.

It is interesting to compare this mixer with a coaxial broadband mixer developed by Sylvania's Electronic Defense Laboratory at Mountain View, California. The cross-section is shown in Fig. 6. It can be seen that the crystal is part of the center conductor of a coaxial line and that the signal and the local oscillator power are fed into opposite ends of this line. The IF output is taken through a thin steel wire to prevent loss of RF energy in the IF circuit. The tangential signal sensitivity of this mixer, when used with an IF amplifier having an effective noise bandwidth of 8.5 mcps is approximately - 90 dbm from 1 to 10 kmc. If this mixer is used with a local oscillator, such as a carcinotron, which contains a loop pickup, the IF cable should then be a quarter of a wavelength long at the IF frequency to prevent a short circuit from appearing at the IF amplifier terminals. For very broadband IF amplifiers (one the order of 100 mc. bandwidth) this is impractical for two reasons: (1) the wavelength of a particular length of cable would vary with frequency, and (2) the capacitance of such a cable would be too large for a broadband IF input transformer. This difficulty is avoided in the microstrip mixer. It is also possible that a portion of the signal energy would be lost in the local oscillator.

For airborne application, the most important advantage of the microstrip mixer lies in the saving of weight and space. It is estimated that this microstrip mixer, whose performance within the octave band is equal to that of a corresponding mixer using a conventional coaxial directional coupler, effects a saving of 50 to 75 per cent in weight.

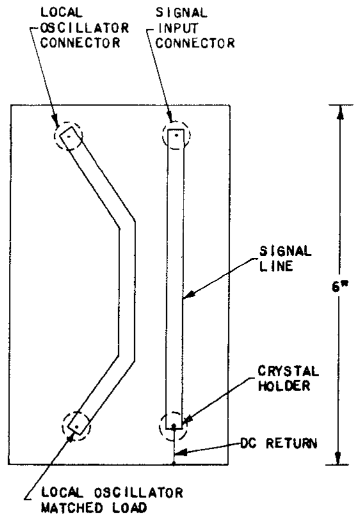

Fig. 1 (left)

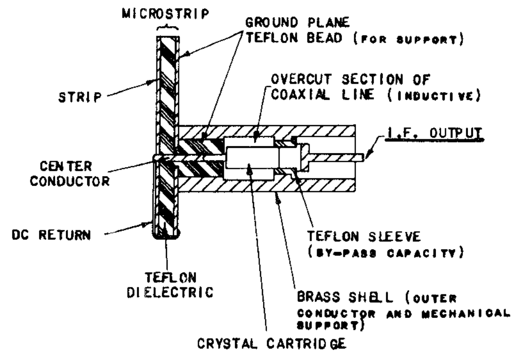

Fig. 1 (right)

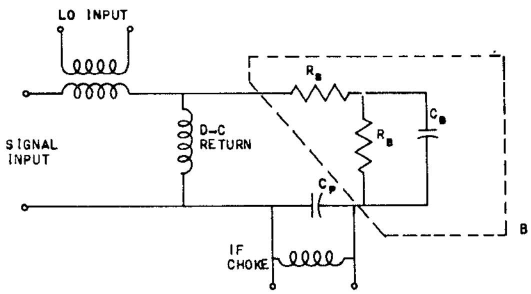

Fig. 2

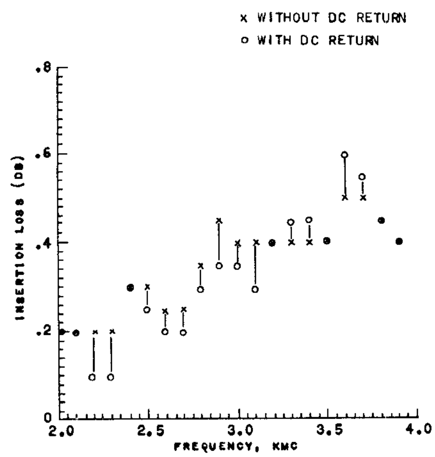

Fig. 4 - Insertion loss of RF input of microstrip directional coupler.

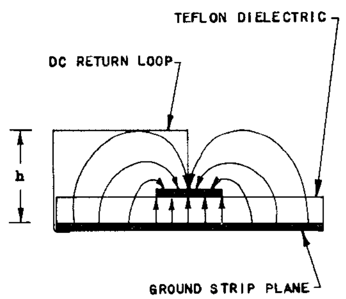

Fig. 3 - Electric field distribution in microstrip.

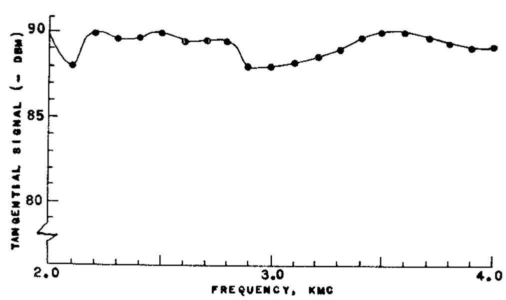

Fig. 5 - Tangential sensitivity of broad band micro-strip mixer with integral DC return.

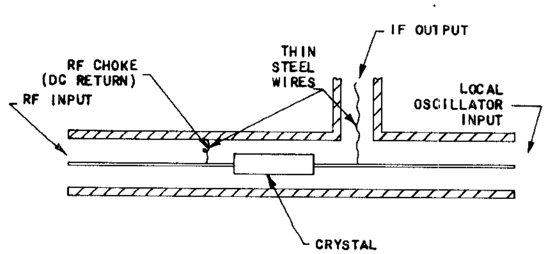

Fig. 6