matching the guide. (Values shown give $\sqrt{L/C}=55$.) This equivalent circuit cannot be altogether satisfactory and Fig. 10 in [1] clearly shows a change in effective varactor inductance which may be indicative of some transformation of junction impedance.

With the more common types of varactor package, the tolerances are frequently so serious that there would be considerable variations in correction factors necessary to deduce the junction values from the impedance close to resonance.

The use of the series resonant condition does not necessarily make it easier to measure varactors by insertion loss than by reflection methods, although commonly used impedance values are not very suitable for the latter. Blake and Dominick [2] have used the transmission-loss method because of the physical separation of their equipment from the mount, since, at a fixed frequency, measurement of loss is simpler. When the frequency is varied, the changes in generator output, in line losses, and in detector sensitivity complicate the measurement of transmission loss unless a balancing path which includes the reference attenuator is used. In such circumstances, for a limited range of frequencies, there is little or no economy in equipment compared with a reflection technique using two balanced paths connected to a precision directional coupler. Phase information is helpful in detailed analysis, and data such as obtained by Roberts is desirable.

There is need for much further work on evaluation of varactors and especially for the development of methods suitable for routine testing, and which can provide useful data on tolerances in packages and junction characteristics.

N. HOULDING
Mitre Corp.
Bedford, Mass.

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Submillimeter Wave Harmonic Mixing

The difference frequency between harmonics of millimeter wave oscillators has been observed at submillimeter wavelengths using a crossed-waveguide harmonic generator[1] as a harmonic mixer.

Figure 1 shows the experimental setup

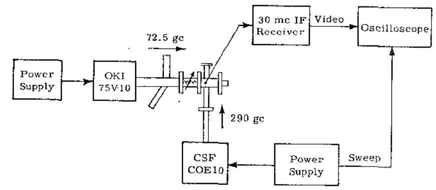

Fig. 1. Harmonics of 72.5-Gc/s klystron mixing with 290-Gc/s carcinotron output and its harmonics.

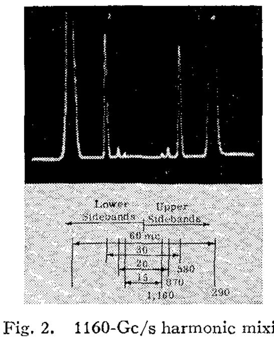

Fig. 2. 1160-Gc/s harmonic mixing.

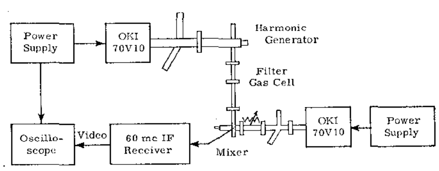

Fig. 3. Harmonic mixing using two 70V10 klystrons.

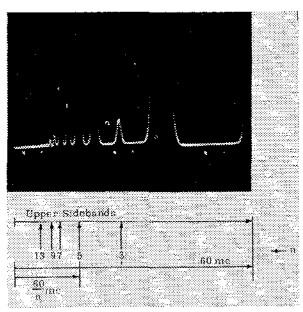

Fig. 4. 950-Gc/s harmonic mixing.

used in mixing the 290-Gc/s output of a carcinotron with the 72.5-Gc/s output of a klystron. The carcinotron was swept about 100 Mc/s and the klystron was operated CW. The difference frequency signals were amplified in a 30-Mc/s IF amplifier and the detected video output was displayed on an oscilloscope. Figure 2 shows the receiver output. Upper and lower sidebands are displayed. The nth harmonic of the carcinotron mixes with the 4 nth harmonic of the klystron to produce IF signals. The upper and lower sidebands are separated by $60/n$ Mc/s on the carcinotron sweep. The highest harmonic observed was the fourth at 1160 Gc/s.

Figure 3 shows the experimental arrangement used in mixing the output from a 72.9-Gc/s klystron with harmonics of a second 72.9-Gc/s klystron. In this case, one crossed-waveguide device was used as a harmonic generator and an identical unit was used as a harmonic mixer. Figure 4 shows the upper sidebands of the receiver output. Thirteen harmonics were observed. A narrow-band receiver is needed to resolve adjacent harmonics. For example, the tenth and twelfth harmonics are separated by 1 Mc/s at the fundamental with a 60-Mc/s IF. In order to determine how many of these harmonics were generated in the multiplier and propagated to the mixer and how many were generated in the mixer, a waveguide filter cutting off the second harmonic was inserted between the multiplier and the mixer. Only the third through sixth harmonics were observed. These were shown to be generated by the multiplier by observing absorptions in a gas cell with carbonyl sulfide, OCS. The signals corresponding to $n=1$ and $n=7$ through 13 were generated in the mixer.

In another experiment, both 72.9-Gc/s klystron outputs were fed in the RG-98 waveguide input of a mixer. One tube was connected to the regular input and the tuning short was removed to accept the second input. In this case so many harmonic beats were observed that the higher harmonics were not resolved. More than 20 harmonics of the 72.9 input were observed.

Harmonic mixing experiments similar to these have been reported by Murai[2] who observed beats as high as 750 Gc/s using a IN53 crystal. A millimeter wave superhetrodyne system using similar techniques was used by Johnson[3] for spectroscopy in the 100- to 150-Gc/s region.

Since 70-Gc/s klystrons can be phase locked to crystal oscillator harmonics, this harmonic mixing technique can be used for accurate measurement of the frequency of submillimeter oscillators (far-infrared lasers) and for phase (or frequency) stabilization of these sources.

R. G. STRAUCH
R. A. MIESCH
R. E. CUPP
Martin Company
Orlando, Fla.

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[1] Devices of this type were first used by spectroscopists to generate millimeter waves from centimeter klystrons. For example, see W. C. King and W. Gordy, *Phys. Rev.*, vol. 93, p. 407, 1954. The units used in these experiments have RG-98 and RG-135 waveguides.

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Magnetostriction Effects in Remanence Phase Shifters

One type of remanence phase shifter[1] consists of a microwave ferrite toroid located in a waveguide. Close mechanical fit between ferrite and waveguide is desirable to eliminate reflection spikes, and to provide an adequate thermal path. Such structures typically develop mechanical pressure on the ferrite, and this pressure may vary with temperature, due to the unequal expansion of the waveguide and ferrite with temperature.

Manuscript received May 25, 1965.

[1] L. Levey and L. Silber, "A fast switching X-band circulator utilizing ferrite toroids," *1950 IRE Wescon Conv. Rec.*, pt. 1, pp. 11–20.