A Novel High-Power Harmonic Suppressor*

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Summary—The use of high-power harmonic suppressors, or low-pass filters, is becoming an accepted technique in the microwave state-of-the-art. The filter to be described is a novel version of the "leaky wall" type.

A _C_-band fundamental frequency harmonic suppressor has been designed with attenuation characteristics verified through the fourth harmonic (K band).

This filter exhibited attenuation of greater than 40 db for several harmonic modes, fundamental frequency insertion loss of less than 0.15 db, an input VSWR of less than 1.15 in the pass band and an input VSWR of less than 2:1 in the stop band. The over-all length of this device is 18 in with a cross section of approximately 7 in × 7 in.

Data on a similar _X_-band low-pass filter are also presented.

INTRODUCTION

THE PHENOMENON of harmonic generation by high-power microwave sources is well known. It arises from the nonlinear behavior of bunched electron beams in these sources. Such harmonics are approximately 30 db below fundamental power levels for second and third harmonics and greatly degrade at the rate of 6 db for higher harmonics. The importance of the spurious signals has been enhanced by the ever increasing power levels obtained in magnetrons and klystrons in the past few years. Concurrently, crowding of the microwave spectrum and improvements in receiver noise figures have further aggravated this problem.

Thus, a *C*-band troposcatter system may interfere with an *X*-band tracking radar by the second harmonic radiation of the *C*-band system being accepted by the *X*-band receiver. Another example would be the interference generated by a high-power *L*-band search radar with other equipments in all bands through *X* band.

Such harmonic generation may even interfere with the receiving function of the same radar by excessive TR-tube leakage of harmonic frequencies, or by high standing waves occurring at the harmonic frequency between the microwave source and another microwave component such as rotary joints. Likewise, standing waves can even damage tube windows, or may lead to intermodulation products in the case of high-frequency communication systems.

Such reactive- and resistive-type harmonic suppressors have been developed by several groups. It has become apparent that reactive filters in waveguide cannot be extended beyond the third harmonic without serious degradation of fundamental frequency-band characteristics.

In addition, filter characteristics originally determined under matched-load generator impedance may no longer be valid due to high standing waves introduced by multiple reflections between this filter and other microwave components.

Considerable design effort has therefore been placed upon the resistive type, the most useful of which is called "leaky wall," to obtain low fundamental frequency insertion loss, low-input VSWR, and high harmonic frequency range attenuation (independent of propagating mode), low stop-band VSWR, and small physical size.

DESIGN APPROACH

In the "leaky wall" harmonic suppressor, the main waveguide is coupled to a large number of secondary waveguides, each of which is below cutoff for the fundamental. These auxiliary transmission lines are terminated resistively for the harmonic frequency range. Since each secondary waveguide only couples weakly to the desired signal, many such coupling structures must be used. In addition, the location of the secondary arms must be distributed so that coupling will occur for all the possible modes existing for the harmonic frequency components for which the main waveguide is greatly oversized.

Although the majority of previously developed harmonic suppressors have used slot coupling between the main and secondary waveguide, the coupling techniques to be described possess a number of advantages. In our arrangement, the secondary waveguides are circular in cross section and are dielectrically loaded. This design approach reduces the physical diameter of the auxiliary waveguides and thereby permits closer packing. This is indicated schematically in Fig. 1.

The dielectric material to be used for loading should have extremely low loss for the fundamental since it will be seen by the high-power signal. We have chosen quartz which possesses the lowest dielectric loss, in dielectric material, in the microwave range. It has a dielectric constant of four, which permits a reduction in auxiliary waveguide diameter by a factor of two. This material is also readily available and can be machined to close tolerances by grinding techniques.

The length of each auxiliary waveguide is calculated to have 30-db attenuation for the highest fundamental frequency component of interest. This insures proper separation between the lossy material in which harmonic signals are terminated and the main waveguide containing the high-power signals. In order to obtain a broad bandwidth for the harmonic, this dielectric rod is allowed to extend into the loaded portion of the

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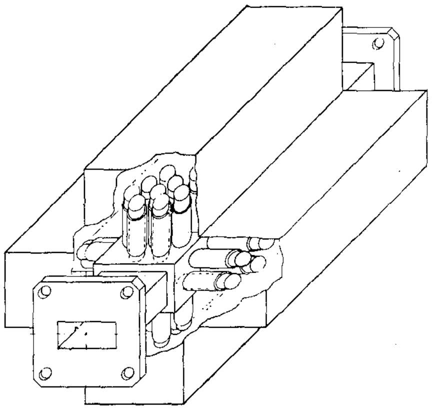

Fig. 1—Schematic of filter construction (harmonic suppressor).

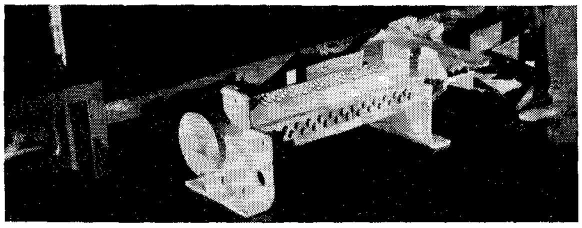

Fig. 2—Filter before installation of quartz rods.

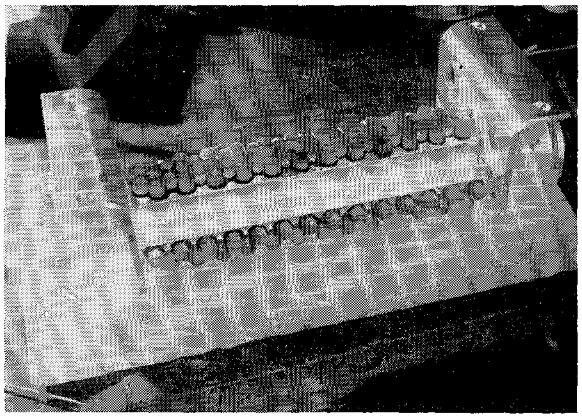

Fig. 3—Filter after installation of quartz rods.

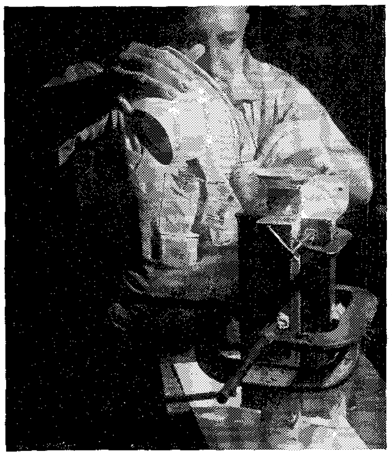

Fig. 4—Pouring epoxy load material.

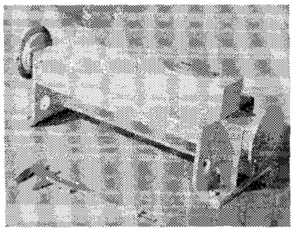

Fig. 5—Completed assembly.

structure. The waveguide with the auxiliary waveguides matched is shown in Fig. 2; and after installation of the quartz rods it is shown in Fig. 3.

The entire unit is next surrounded by a sheetmetal cover and a suitable load material is poured into the cavity so formed. Fig. 4 shows this procedure. Load material consists of a loaded epoxy resin which is cured in place. The completed assembly is shown in Fig. 5.

TEST PROCEDURE

The "leaky wall" structure was placed on all four sides of the main transmission line in order to assure coupling to all modes in which the harmonic signals may propagate.

To determine the performance of such a harmonic for each of the mathematical possibilities of higher-order modes is clearly a large task. We have therefore selected three modes to form a representative picture and it may be argued qualitatively that satisfactory attenuation for these three modes should assure satisfactory attenuation for even more complicated configurations.

Fig. 6 shows a selection of mode launchers to permit excitation of the TE_{10} mode, the cross-polarized TE_{01} mode and the TE_{20} mode. Although no tests were made to determine purity of these launchers, it was felt that the desired mode was certainly predominant.

Attenuation measurements were performed in an arrangement indicated schematically in Fig. 7. The

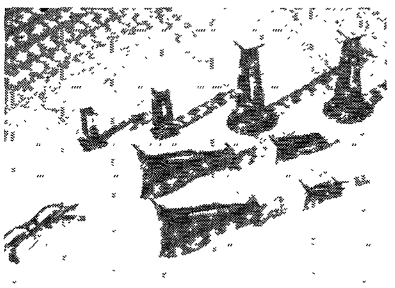

Fig. 6—Selection of mode launchers.

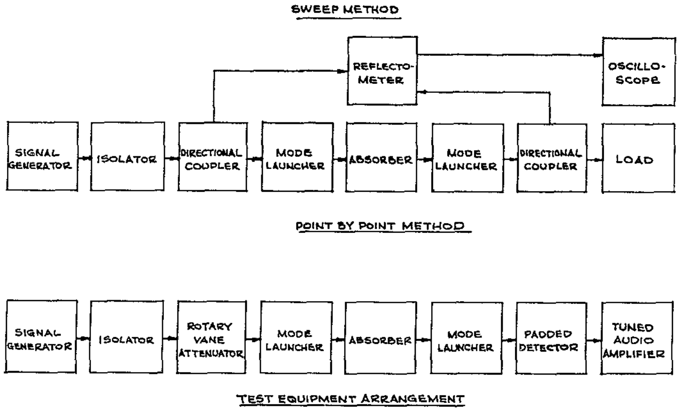

Fig. 7—Schematic illustration of attenuation measurement set up.

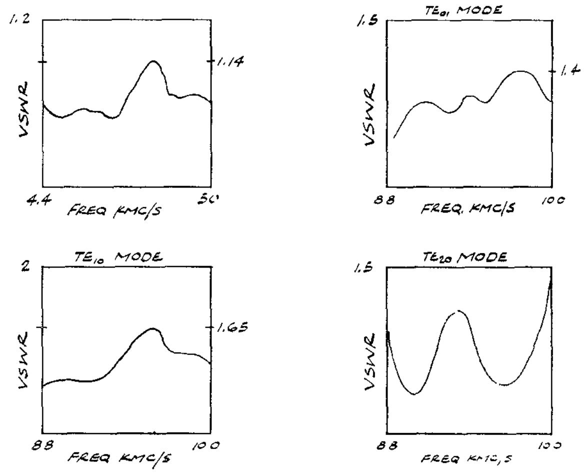

Fig. 8—Reproduction of oscilloscope traces input VSWR.

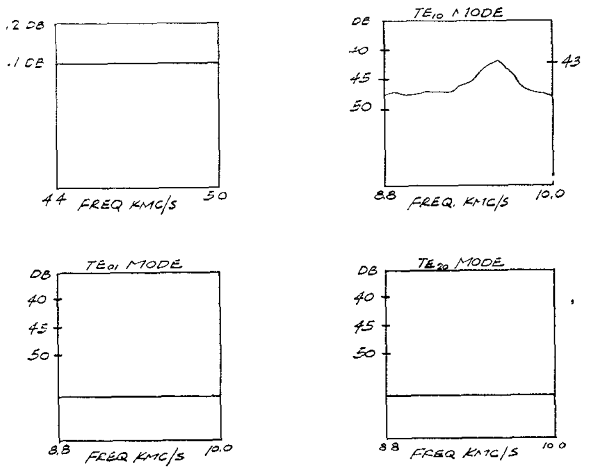

Fig. 9—Reproduction of oscilloscope traces insertion loss.

	Fundamental Frequency Range	Second-Harmonic Frequency Range			Third-Harmonic Frequency Range			Fourth-Harmonic Frequency Range		
	4.4–5.0 kMc	8.0–10.0 kMc			13.2–15.0 kMc			17.6–20.0 kMc		
		TE_{10}	TE_{01}	TE_{20}	TE_{10}	TE_{01}	TE_{20}	TE_{10}	TE_{01}	TE_{20}
		MODE			MODE			MODE		
Insertion Loss (db)	0.15	>43	>55	>54	>50	>50	>50	>51	>40	>40
Input VSWR	<1.14	<1.65	<1.4	<1.45	<1.4	<1.5	<2	<1.5	<2	<2
Size 18 in.×7 in.×7 in.										
Weight 35 lbs.										
2nd-harmonic absorption per unit length		4.3 db/in of active length								
2nd-harmonic absorption divided by fundamental loss		>250 db per db								

Fig. 10—Table of device characteristics: figure of merit—*C*-band low-pass characteristics.

	Fundamental Frequency Range	Second-Harmonic Frequency Range			Third-Harmonic Frequency Range			Fourth-Harmonic Frequency Range
	10–11 kMc	20–22 kMc			30–33 kMc			40 kMc
		TE_{10}	TE_{01}	TE_{20}	TE_{10}	TE_{01}	TE_{20}	TE_{10}
		MODE			MODE			MODE
Insertion Loss (db)	0.10	>22	>22	>26	>30	>31	>35	>30
Input VSWR	<1.12	<2	<2	<2	<2	<2	<2	<2
Size	6¾ in×4 in×4 in for 20 db Model	21 in×4 in×4 in for 70-db Model						
Weight	6 lbs	18 lbs						
2nd-harmonic absorption per unit length		6.5 db/in of active length						
2nd-harmonic absorption divided by fundamental loss		>250 db per db for 70-db Model						

Fig. 11—Table of device characteristics: figure of merit—*X*-band low-pass absorption filter.

detector used was merely a level-indicating device with readings taken on a rotary vane attenuator to obtain the same power level with or without the harmonic suppressor in the line. For second harmonics, sweep techniques were used to verify suppressor performance. In effect, sweep eliminates the possibility of missing narrow ranges where performance may not be up to specification. Figs. 8 and 9 show reproductions of oscilloscope traces obtained in this test. Figs. 10 and 11 show a table of device characteristics for higher frequency ranges where sweep equipment was not available.

CONCLUSIONS

Two different harmonic suppressors finalizing the above design principle have been developed, one operating in C band, and the other in X band. Up to this date these have only been tested at high CW power levels and no peak power breakdown data exists. Figs. 10 and 11 also show a summary of important device parameters such as size and weight, attenuation per unit length, and a figure of merit which has been defined as attenuation for the second harmonic divided by attenuation for the fundamental. This figure of merit cannot be approached by reactive filters or by ferrite devices.

A Plasma-Column Band-Pass Microwave Filter*

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Summary—A tunable band-pass filter using the dipole resonance of a plasma column has been investigated. The center frequency of the pass band can be electronically tuned over a large portion of a waveguide band. For the prototype investigated at S band, the insertion loss at the center frequency was less than 2 db, with isolation for frequencies outside the pass band on the order of 12 db. A typical 3-db bandwidth of this prototype was 150 Mc. It is expected that this figure can be improved by choice of better discharges than the positive column of the mercury discharge used here.

An analysis of the external Q's for the input and output coupling is presented. From these calculations, it is possible to determine approximately the various coupling parameters that produce a given degree of overcoupling.

I. INTRODUCTION

BAND-PASS filters that can be electronically tuned over a wide band are desirable components in some present-day electronic systems. Several schemes have been proposed and investigated for achieving such filters. In most cases these have involved resonant cavities which are perturbed and tuned by a variable impedance element, such as a voltage variable capacity diode,[1] ferrite,[2–4] or ferroelectric.[5] A much wider tunable bandwidth can be obtained, however, by use of a material which itself exhibits a resonance effect. A particularly successful example of this is the magnetically tunable yttrium iron garnet filter investigated by Carter,[6] in which the spin resonance is used as a microwave resonator. The resonance exhibited by the plasma column can be used to make an electronically tunable filter in a similar way. This paper discusses the mechanism of such a filter and experimental results of a prototype filter constructed at S band. While results for this prototype certainly do not rival those that have been achieved with the yttrium iron garnet filter, it is possible that the principle of the plasma filter may also find applications.

The plasma resonance used in our filter is that previously investigated by Tonks[7] and more recently by others, in particular by Dattner.[8] The simplified physical picture of the resonance is that of a cylindrical electron cloud oscillating about a stationary cylindrical ion cloud. This resonance can be treated as that of a microwave resonator, whose resonant frequency is a function of the plasma density.

The resonance of a plasma column is easily excited by passing the column through a TE_{10} rectangular waveguide, such that the column axis is perpendicular to the incident electric field and to the direction of propagation. By positioning a pick-up probe so that it is only excited when the column is in resonance, a band-

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[1] A. Uhlir, Jr., "The potential of semiconductor diodes in high-frequency communications," PROC. IRE, vol. 46, pp. 1099–1115; June, 1958.

[2] G. R. Jones, J. C. Cacheris, and C. A. Morrison, "Magnetic tuning of resonant cavities and wideband frequency modulation of klystrons," PROC. IRE, vol. 44, pp. 1431–1438; October, 1956.

[3] C. E. Fay, "Ferrite-tuned resonant cavities," PROC. IRE, vol. 44, pp. 1446–1449; October, 1956.

[4] C. E. Nelson, "Ferrite-tunable microwave cavities and the introduction of a new reflectionless, tunable microwave filter," PROC. IRE, vol. 44, pp. 1449–1455; October, 1956.

[5] W. J. Gemulla and R. D. Hall, "Ferroelectrics at microwave frequencies," *Microwave J.*, vol. 3, pp. 47–51; February, 1960.

[6] P. S. Carter, Jr., "Magnetically-tunable microwave filters using single-crystal yttrium-iron-garnet resonators," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-9, pp. 252–260; May, 1961.

[7] L. Tonks, "The high-frequency behavior of a plasma," *Phys. Rev.*," vol. 37, pp. 1458–1483; June 1, 1931.

[8] A. Dattner, "The plasma resonator," *Ericcson Technics* (Stockholm), vol. 13, pp. 310–350; 1957.