FURTHER ADVANCES IN HIGH-POWER ELECTRONICALLY TUNED RESONATORS

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Abstract

A new technique for electronically tuning a high-Q resonator was investigated, based on the use of heavy-duty PIN diodes to short out inductive elements that are in series with the transmission line in a half-wavelength cavity. Design relationships were developed and validated for a high-power UHF resonator operated as a bandpass filter. The internal volt-ampere rating of the resonator is 640 kVA, which allows the filter to accommodate 4 kW of RF input power at 0.8% instantaneous loaded bandwidth. The unloaded Q was maintained in the vicinity of 2000 for the 11% tuning range, 350 to 391 MHz.

Introduction

One important application for high-power electronically tuned resonators is in association with the transmitters of frequency-agile communications systems. The "fast-tuned" resonator would be used either as the tank circuit of the transmitter output amplifier or as a bandpass filter inserted between the transmitter and its antenna. When so used, the resonator prevents spurious wideband energy from reaching the antenna and also provides isolation for collocated transmitters and receivers. Mechanical tuning of the resonator is ruled out by the brevity of the allowable tuning time (at most a few tens of microseconds), while varactor or YIG tuning is applicable only at milliwatt levels of RF power, especially when extremely little distortion is allowable. Since RF power levels in the current work actually extend to several kilowatts, CW, tuning is being accomplished in discrete frequency steps through the use of rugged and heavily biased PIN diodes.

The resonator RF power rating, P_0, is significant only in association with the loaded Q, Q_L (the reciprocal of the instantaneous fractional loaded bandwidth), because the very large RF currents and voltages that build up internal to the resonator are each proportional to $(P_0Q_L)^{\frac{1}{2}}$. Also important is the total tuning range, since the stresses experienced by the tuning devices (PIN diodes) within the resonator increase with this quantity, as do the contributions of the diode-loss resistances to the resonator unloaded Q, Q_u. Thus, the achievement of a CW power rating of at least 1.5 kW (and very likely as much as 4 kW) for the UHF bandpass filter resonator developed most recently[1,2] is significant in view of the instantaneous loaded bandwidth of 0.8% ($Q_L \approx 125$), a total tuning range of about 11% (350 to 391 MHz), and the unloaded-Q values $1700 < Q_u < 2560$. (The filter insertion loss is thus only 0.5 to 0.6 dB.)

Although the resonator was developed for the UHF band, microwave techniques are being used because the cavity is a half-wave section of coaxial line, and the basic diode-controlled tuning element (discussed below) is a radial-line stub. In previously reported work,[3,4] a high-power resonator was described in which electronic tuning was achieved by lightly and distributively loading a half-wave coaxial-line cavity with shunt-capacitive irises containing PIN diodes. Since the N irises used were installed in such a way that a binary-scaled series of tuning increments was generated by the reversal of state of the diodes in the series of independent irises, 2^N tuning channels were obtained. As reported, the final result of this capacitive-iris-tuning (C-type Flauto) project was a two-cascaded-resonator filter with 128 well tracked tuning channels. The total tuning range was 355 to 400 MHz (12%), and Q_u values near 1000 were maintained in each resonator. With Unitrode UM 7010 C PIN diodes in the iris subject to the greatest RF voltage stress, the RF power rating was 100 W, CW, with $Q_L \approx 125$ for each resonator.

Since Q_L and the tuning range have remained essentially the same for the recent and the previous work, it may properly be noted that more than an order of magnitude increase in RF power rating has been achieved along with a significant improvement in Q_u. The recent work was based on a new electronic-tuning concept and included analytical and experimental studies. With a feasibility-model bandpass filter, the correctness of the modeling relationships was confirmed and the desired electrical performance was demonstrated most satisfactorily.

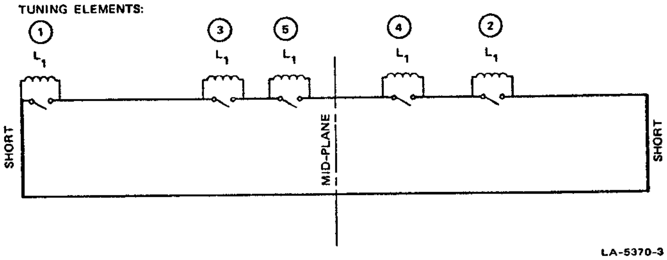

FIGURE 1 "L-FLAUTO RESONATOR TUNING SCHEME. Transmission-line segment distributively loaded with switchable series inductances, providing a series of binary-scaled tuning increments. Switch parasitics and external coupling to resonator not shown.

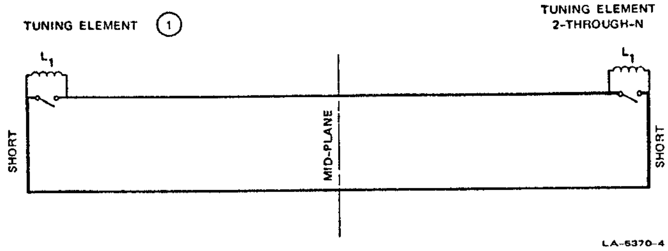

FIGURE 2 RESONATOR OF FIGURE 1 SIMPLIFIED FOR FEASIBILITY DEMONSTRATION PURPOSES. Tuning element at right end is surrogate for Tuning Elements 2, 3, 4, ..., N. Switch parasitics and external coupling to resonator not shown.

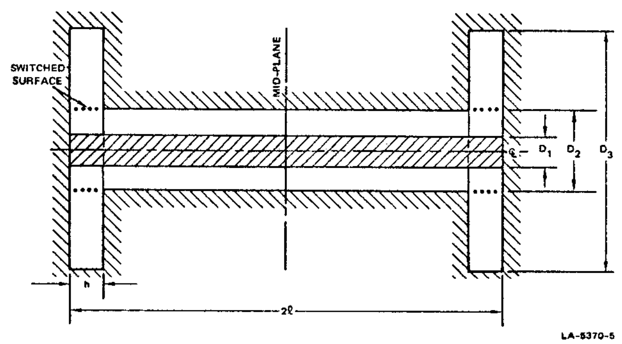

FIGURE 3 BASIC CONFIGURATION OF RESONATOR FOR FEASIBILITY DEMONSTRATION

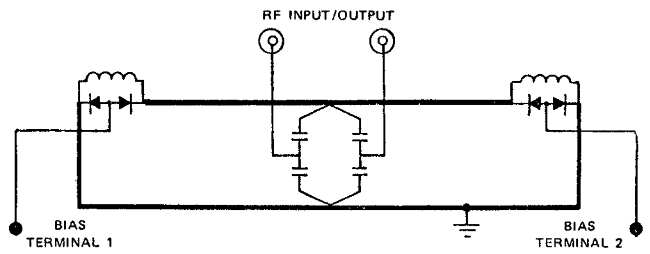

FIGURE 4 SCHEMATIC REPRESENTATION OF FILTER RESONATOR FOR FEASIBILITY DEMONSTRATION

New Approach to Tuning

For the new work, the principle of duality was implemented, so the "L-type Flauto" tuning scheme investigated was based on inductive elements inserted in series with the transmission line that forms the main resonator.[5] As shown in Figure 1, each inductive element may be independently shorted out by a switch. (The details of the arrangement of PIN diodes comprising the switch, and the diode parasitics, are omitted for clarity.) Switching the inductive element closest to a shorted end of the resonator would provide the most significant tuning increment; the other tuning elements would provide progressively smaller tuning increments (according to a binary program).

To save time and expense, the feasibility-model resonator was simplified by using a duplicate of Tuning Element 1 as a surrogate for all the less-significant (2 through N) tuning elements. This can be done because of the properties of a binary-scaled series of elements and does not affect any of the Q parameters of the resonator, nor the total tuning range, nor the power rating. Figure 2 represents the electrical essentials of the feasibility-model resonator (with switch parasitics omitted). Although this model can have tuning channels only at the top, bottom and middle of the tuning range, the fast-tuned resonator is characterized adequately for the purpose of demonstrating feasibility.

The physical essentials of the feasibility-model resonator are illustrated in Figure 3. The main resonator is coaxial (Z_0 = 63 ohms) and about a half-wavelength long at the upper end of the tuning range. The inductive tuning elements are provided by radial-line stubs joined onto the main resonator as shown. The entrance to each stub is spanned by an array of Unitrode UM 4010 C PIN diodes that effectively forms a cylindrical "switched surface" which can either block or unblock the entrance to the radial line. The diodes in the array have cathodic heat sinks, and are used in pairs, anode to anode, so that bias may be applied to the anode common point without the use of chokes. As illustrated schematically in Figure 4, the diodes in each pair are thus in parallel for bias, but in series with respect to RF voltages and currents. Each diode symbol in Figure 4 represents a parallel combination of six diodes, uniformly distributed around the circle whose diameter is D_2.

Figure 5 shows some of the constructional details of an initial developmental filter resonator with which feasibility of the new tuning concept was successfully demonstrated. As indicated in Figures 4 and 5, adjustable capacitive probes were chosen, as a matter of convenience, to provide input and output couplings to the resonator.

Results

The resonator under analytical and experimental investigation was readily modeled, and a set of design relationships was developed easily. The residual inductance of a forward-biased diode is small enough to be neglected or accounted for by a minor correction. The residual diode resistance, R_s, which is a function of the forward bias current, determines RF power dissipation in the diodes and the overall resonator Q_u. This Q_u (under forward bias) increases as more diodes are paralleled.

Under reverse bias, the residual capacitance of a diode has an effect that is sufficiently small to neglect or to account for with a minor correction. An equivalent shunt resistance, R_p, which varies somewhat with frequency and bias voltage, determines diode losses in this case, and hence a new value of Q_u that increases as fewer diodes are paralleled. Equations that show the relation of Q_u (for both diode states) to the several parameters involved (including those representing resonator wall losses as well as diode losses) are important to the resonator design--one objective of which is to maintain Q_u at as high a value as practical over the entire tuning range.

Under reverse bias, a large RF voltage exists across each diode. The allowable RF voltage is limited by the diode voltage rating and the dc bias voltage applied. The peak RF voltage per diode, $\hat{V}_1$, is

$$\hat{V}_1 \approx \left(\frac{2}{\pi} Q_L P_0 Z_0\right)^{\frac{1}{2}} \cot\left(\frac{\pi}{2}\frac{f_A}{f_B}\right)$$

where the overall tuning range is f_A to f_B. In consideration of the reverse-breakdown characteristics observed for the 24 type UM 4010 C diodes installed,[6] a power rating of $P_0 \approx 4$ kW (with $\hat{V}_1 \approx 800$ V) is indicated by the above equation. Testing was not carried out beyond 1.5 kW, however, because the necessary transmitter power was not available. To prevent excessive diode temperatures from occurring during CW operation, due to the RF power dissipated within the diodes, aluminum cooling fins were incorporated as appropriate into the design of Figure 5, though not shown in the sketch.

Conclusions

The feasibility-model resonator (whose performance parameters are summarized in Table I) along with the pertinent modeling relationships can serve as a guide for future development.[7] Most importantly, a new technique has been demonstrated for electronically tuning a UHF or microwave resonator (whether for a filter or other application) over a useful tuning range while maintaining high levels of RF power rating and loaded and unloaded Q.

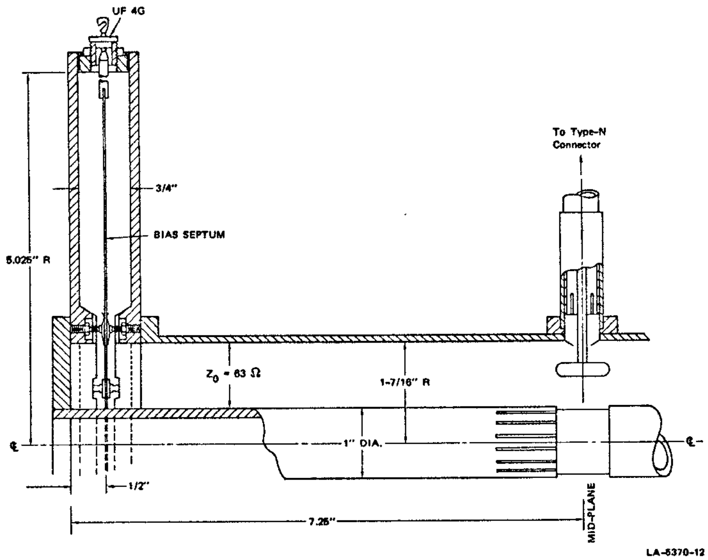

FIGURE 5 CONSTRUCTIONAL DETAILS OF DEVELOPMENTAL ELECTRONICALLY TUNED UHF FILTER RESONATOR

Table I

PERFORMANCE PARAMETERS OF FEASIBILITY-MODEL FILTER RESONATOR

Diode bias states	All reverse	Reverse in one tuning element; forward in the other	All forward
Resonant frequency	349.8 MHz	368.0 MHz	391.0 MHz
Q_u	2560	2020	1700
Q_L	152	126	108
3-dB bandwidth	0.66%	0.79%	0.93%
Insertion loss	0.52 dB	0.58 dB	0.62 dB
VSWR	1.13	1.13	1.14
RF input power			
Rated	4 kW	4 kW	4 kW
Applied to date	1.5 kW	1.5 kW	1.5 kW

Acknowledgments

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Notes and References

1. The sponsor has been Rome Air Development Center, Air Force Systems Command (Contract F30602-76-C-0248).

2. A. Karp, "Electronically Tunable UHF High-Power Filter," Final Report, Contract F30602-76-C-0248, SRI Project 5370, Stanford Research Institute, Menlo Park, Calif. (February 1977).

3. A. Karp and L. N. Heynick, "UHF Electronically Tunable High Power Filter," Final Report, Contract F30602-74-C-0142, SRI Project 3321, Stanford Research Institute, Menlo Park, Calif. (September 1975).

4. A. Karp and W. B. Weir, "Recent Advances in Binary Programmed Electronically Tunable Bandpass Filters of the 'Flauto' Type," pp. 167-169, Digest of Papers for the 1975 MTT-S International Symposium, Palo Alto, Calif., May 1975.

5. The usefulness of both C- and L-type resonator-tuning approaches was anticipated at an early date by D. B. Leeson. See "Digital Tuning Imposes Will on Cavity Oscillators," MicroWaves, Vol. 8, No. 7, pp. 62 and 118-119 (July 1969); and D. B. Leeson, "Digital Tuned Microwave Oscillator," U.S. Patent 3,755,758 (28 August 1973).

6. As a result of detailed experimentation in which Q_u values were measured with "dummy" as well as actual diodes installed, it became evident that R_s = 0.05 ohm (at 1.5 A of forward bias current) and R_p = 70,000 ohms (near 350 MHz and under sufficient reverse bias voltage) are the loss resistances applicable to the diodes used.

7. For example, all transverse dimensions (Figure 5) can be halved without affecting diode dissipation, while the reduction in Q_u due to the increased resonator wall losses can be readily predicted and shown to lead to an increase of only a few tenths of a dB in the insertion loss. Moreover, if the number of diode pairs used per tuning element is increased from 6 to 8, it can be predicted that Q_u will be more nearly constant (and hence maximal) over the tuning range.