RECENT ADVANCES IN BINARY-PROGRAMMED ELECTRONICALLY-TUNABLE BANDPASS FILTERS OF THE "FLAUTO" TYPE

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Abstract

Two half-wave resonators with binary-programmed, high-speed electronic tuning have been cascaded to form a second-order high-power bandpass filter for the range 355 to 400 MHz. Seven binary-scaled, PIN-diode-controlled, tuning irises in each resonator provide a maximum tuning increment of 550 kHz while the tracking error never exceeds 150 kHz. Extensive improvements were made in design and performance, and in automatic control and testing, over previous work with a single resonator of more primitive design.

Introduction

The high-selectivity bandpass filters discussed here were initially developed for aircraft communications systems requiring the insertion of these filters between a transmitting antenna and a frequency-agile solid-state transmitter operating at a non-pulsed output level of the order of 100 W. To date, the UHF band (225 to 400 MHz) has been the frequency range of interest. However, since the heart of each filter is a half-wave transmission-line resonator, distributively loaded with waveguide irises, it is clear that microwave techniques are being used. In addition, application of the design principles at L-band or S-band (and to low-power as well as high-power applications) appears highly feasible.

In the earlier work[1] the essential features of a single-resonator "Flauto" bandpass filter were demonstrated.* These included the use of N binary-scaled tuning irises to generate 2^N tuning channels, the use of PIN-diode switching to make each capacitive tuning iris double-valued (at high RF power levels), mathematical modeling covering the novel tuning scheme and also the effects of diode losses, and the development of control hardware and software enabling a HP 8541A Automatic Network Analyzer to automatically tune the filter and measure performance parameters at all its tuning channels.[2]

*The name "Flauto" was chosen because the filter resonator is analogous to that of a flute, recorder, or other woodwind. These musical instruments (unlike the slide trombone or multiresonator organ, for example) have a single, fixed-length resonator that can have a large gamut of resonances thanks to a small number of independent two-valued reactive perturbations--the open-or-closed finger holes.

Recent Advances

In recent work (under RADC Contract F30602-74-C-0142) the principal advance has been the cascading of two resonators, requiring multichannel electronic tuning of the two resonators with minimal tracking error. In addition, extensive improvements over previous work were made in mechanical and electrical design and in performance of the individual resonators. Also, new control hardware and software were developed to achieve high-speed all-solid-state tuning and complete tuning, testing, and performance data processing and display for the multichannel second-order filter by the newer HP 8542B Automatic Network Analyzer.

Figure 1 shows two correctly-interconnected resonators for the frequency range 355 to 400 MHz. The RF power rating minimum design objective is 80 W, CW. Each resonator has 2^7 or 128 tuning channels with a maximum tuning increment of 550 kHz. This alone could permit the resulting second-order filter to have at least 100 tuning channels wherein the tracking error would not exceed 275 kHz, although the two resonators might not be tuned by the same list of codes. However, it has been found entirely feasible in practice to apply the same tuning code to each resonator and to obtain tracking errors not exceeding 150 kHz. Each channel has a passband insertion loss of about 2.5 dB, a VSWR less than 1.25, and 3-dB and 40-dB bandwidths of about 2 and 22 MHz, respectively.

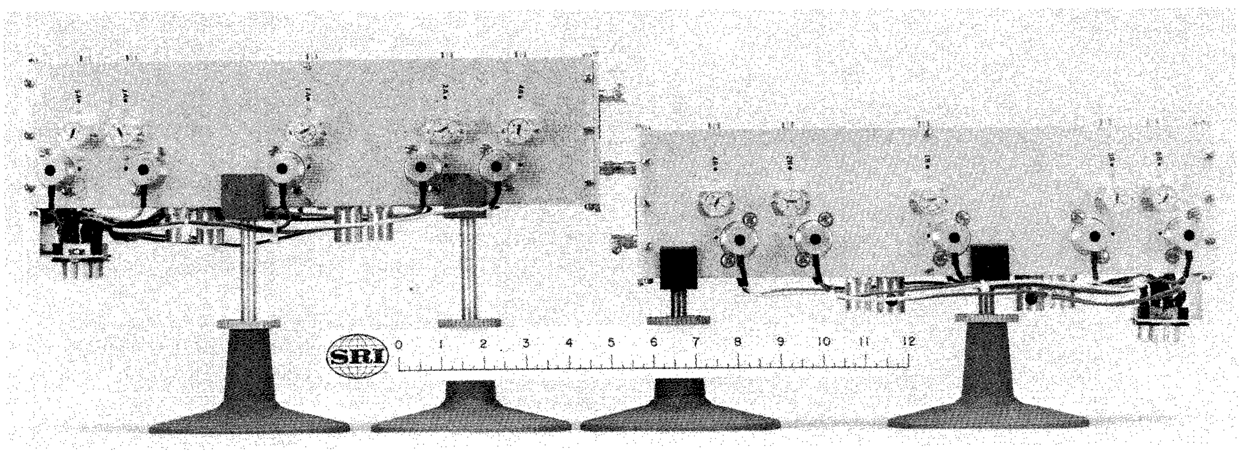

FIG. 1. SECOND-ORDER HIGH-POWER BANDPASS FILTER (355 to 400 MHz) WITH HIGH-SPEED ELECTRONIC TUNING, COMPRISING 2 RESONATORS WITH 7 BINARY-SCALED TUNING IRISES EACH.

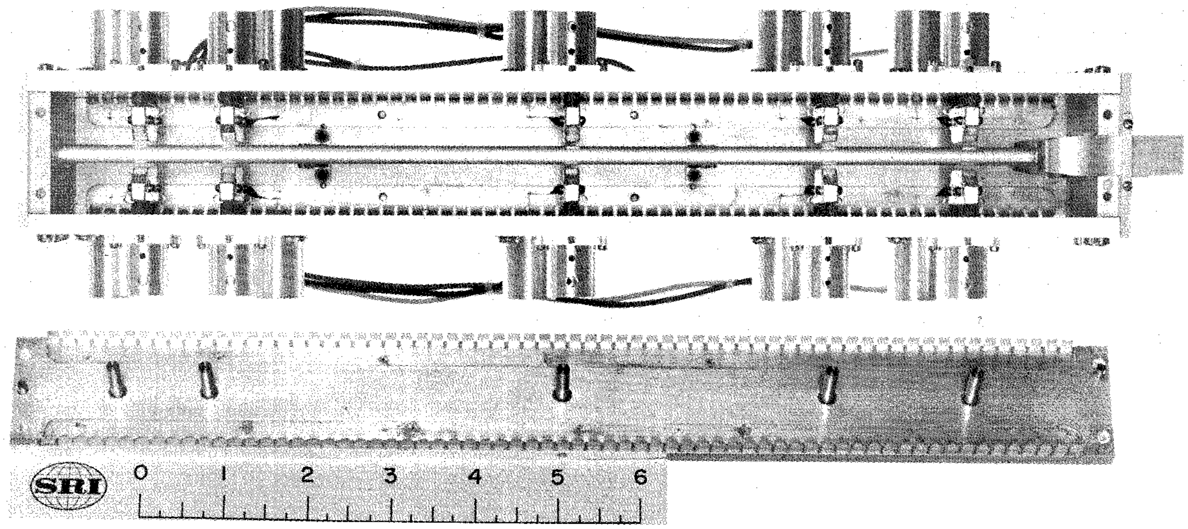

FIG. 2. INDIVIDUAL BINARY-PROGRAMMED 128-CHANNEL RESONATOR PARTIALLY DISASSEMBLED. (Coupling loops are at right end. Fine-tuning irises are only partially visible at rear. Exterior cylinders house bias chokes and gap-adjusting mechanisms.)

Figure 2 shows the interior of an individual resonator, with its five coarse-tuning irises clearly visible. The cross-section views of Figure 3 show that the resonator uses a quasi-coaxial TEM transmission line, and also how a coarse-tuning iris, and its PIN diodes, are positioned relative to the inner conductor. With the diodes forward biased, the iris clearly has a larger effective capacitance than when the diodes are reverse biased. (Bias is applied through the bias chokes and leads seen in Figs. 1 and 2 but not in Fig. 3.) The polarity of the diode bias for each iris determines the tuning. The magnitude of the forward bias current per diode and of the reverse bias voltage determines the RF power rating of the filter and also the contribution of the diode losses to the unloaded Q, Q_u, of the resonator. The use of four UM-7000-series diodes in each iris allows the Q_u at the bottom and top of the tuning range (each determined almost entirely by the RF diode resistance under forward and reverse bias, respectively) to be about the same and equal to 1000.

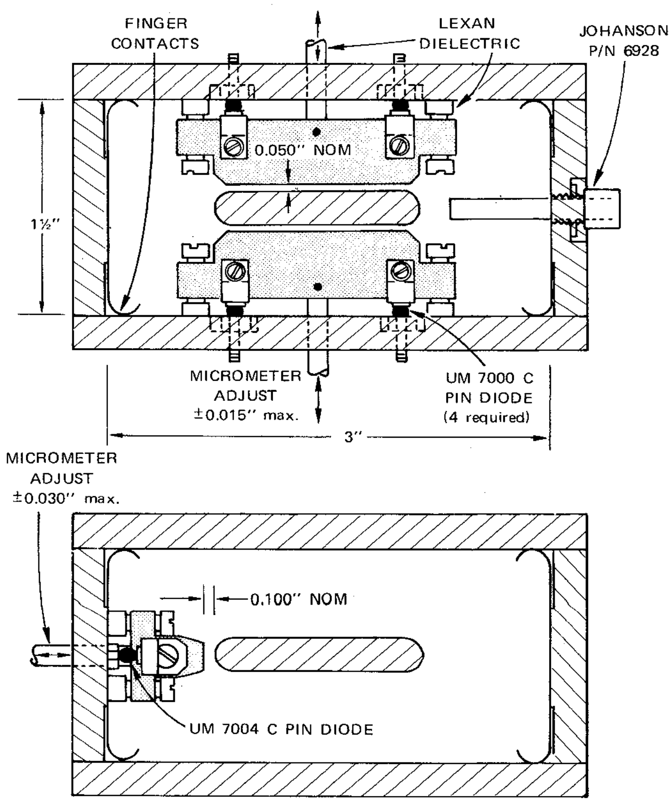

FIG. 3. CROSS-SECTIONS OF RESONATOR SHOWING COARSE-TUNING IRIS (upper sketch with auxiliary tuning screw at right) AND FINE-TUNING IRIS (lower sketch). [Bias chokes not shown.]

Although all five coarse-tuning irises are identical, their tuning effectiveness (i.e., the change in resonator frequency resulting from a reversal of diode bias in each) follows a binary program. The fact that the reversal of diode bias in iris n changes the resonator frequency by $1/2^n$ of the total tuning range is due to the axial positioning of the irises within the half-wave resonator, as discussed in Reference 1.

The division of the tuning range into 31 almost-equal frequency intervals is improved upon by a relatively minute "trimming" (< ±10%) of the coarse-tuning iris gaps. Each of these intervals is further subdivided into four tuning increments by binary-scaled fine-tuning irises 6 and 7, constructed as shown in Fig. 3. All irises are included in Figs. 1, 2, and 4, which is the equivalent circuit.* Interaction between a coarse-tuning iris and a fine-tuning iris is undesirable; it becomes negligible with the arrangement illustrated. The optimal "trimming" of all iris gaps is now carried out fairly rapidly by following a rational methodology aided by computer display of relevant parameters obtained during the automated test procedure.

The transistorized PIN-diode-driving circuitry for the filter has a switching-time design objective of 10 μsec. For the case of control by the HP 8542B Auto-

*The higher the number of the iris, the less significant it is to the Q_u and the RF power rating of the resonator. Consequently, cheaper diodes and reduced biases can be used. This feature is a desirable economic correlate of the "Flauto" concept.

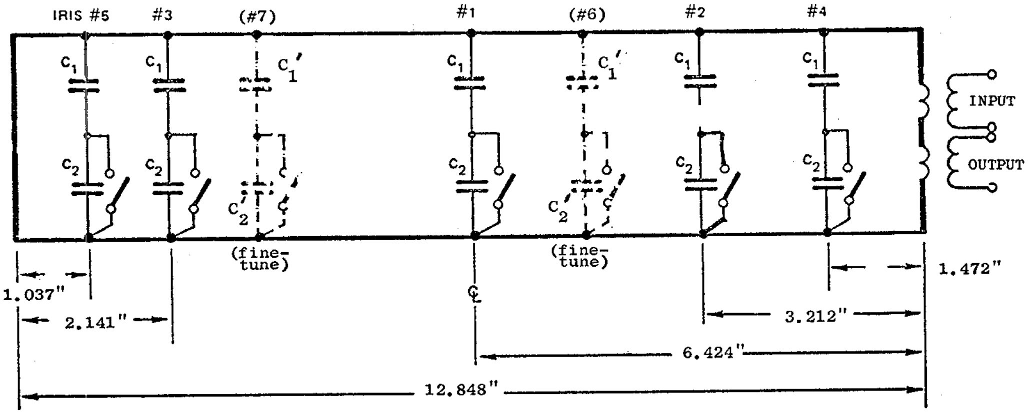

FIG. 4. EQUIVALENT CKT. OF FILTER RESONATOR NEGLECTING ALL SOURCES OF LOSS. [TEM-line resonator distributively loaded with independent switch-controlled capacitive irises.]

matic Network Analyzer, software was developed for the automatic tuning of single- and double-resonator filters, the measurement of performance parameters for each tuning channel, and the processing and display of these data. Typical outputs of performance data for the second-order filter are shown in Figs. 5 through 7. (For the single-resonator case, plots of loaded, unloaded, and external Q may also be outputted.)

Conclusions

The application of microwave techniques in the development of an unusual communications-system filter has been outlined above. The use of solid-state devices (PIN diodes) and of novel microwave measurement techniques, with computer assistance throughout, may also be noted.

Acknowledgments

Inestimably significant contributions to the above work were made by Louis N. Heynick, Eldon J. Fernandes, Robert Pierce, York Sato, Kenneth H. Kerwin and others at SRI and by Capt. John Erickson of RADC.

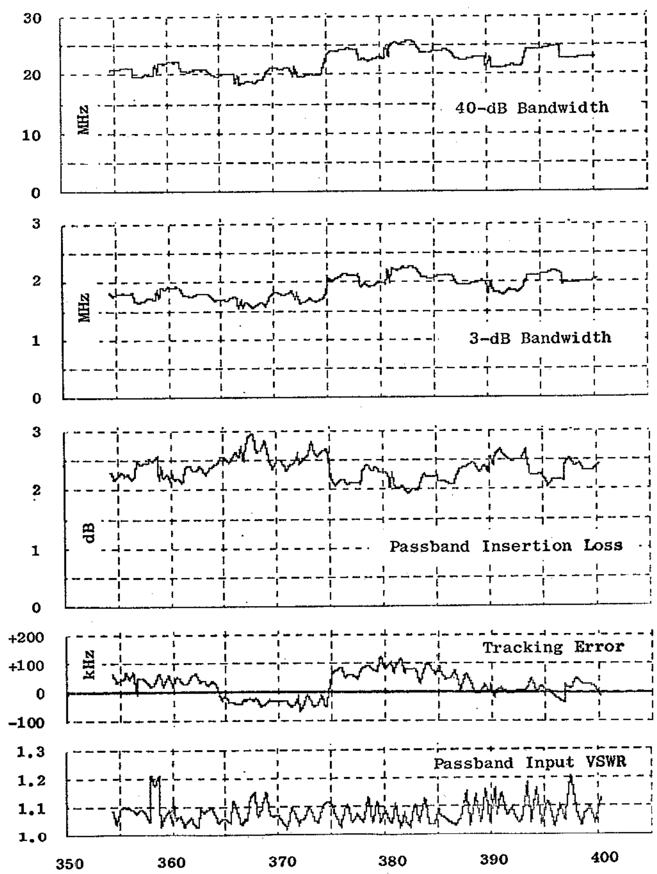

FIG. 5. MEASURED PERFORMANCE PARAMETERS FOR ALL 128 POSSIBLE CHANNELS OF SECOND-ORDER BANDPASS FILTER OF FIG. 1.

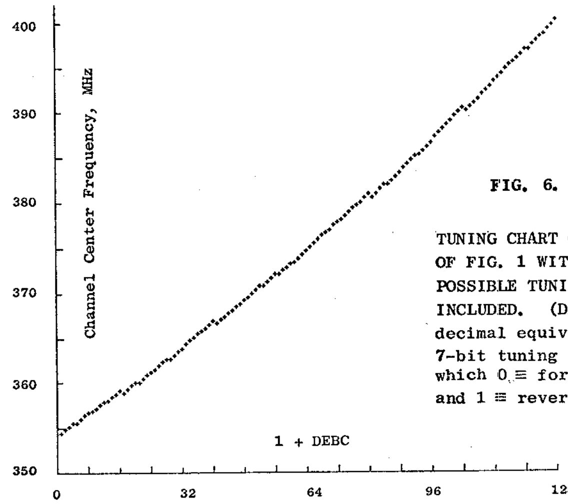

FIG. 6.

TUNING CHART OF FILTER OF FIG. 1 WITH ALL POSSIBLE TUNING CODES INCLUDED. (DEBC ≡ decimal equivalent of 7-bit tuning code in which 0 ≡ forward bias and 1 ≡ reverse bias.)

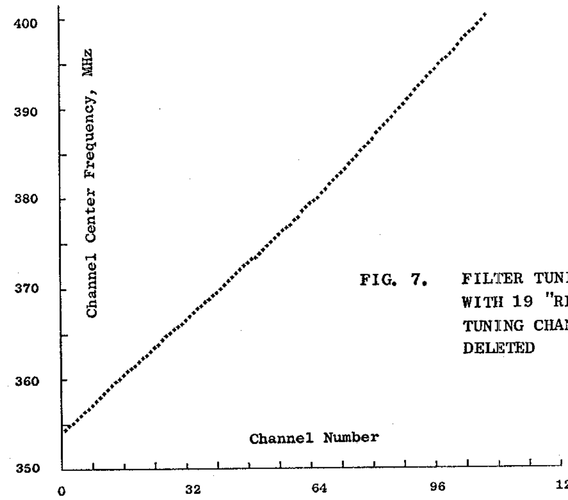

FIG. 7. FILTER TUNING CHART WITH 19 "REDUNDANT" TUNING CHANNELS DELETED

References

1. A. Karp, "Flauto: A High-Power, High-Q Bandpass Filter with Binary Logic Electronic Tuning," IEEE Trans. Microwave Theory Tech., awaiting publication. (See also "Electronically Tunable High-Power Filter for Interference Reduction in Air Force Communication Systems," Final Report, RADC Contract F30602-71-C-0255, SRI Project 1201, Stanford Research Institute, Menlo Park, California, June 1972.)

2. W.B. Weir, "Automatic Measurement System for a Multichannel Digitally-Tuned Bandpass Filter," IEEE Trans. Instrum. and Meas., Vol. IM-23, No. 2, pp. 140-148, June 1974.