A Miniature Tuned Reed Selector of High Sensitivity and Stability

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This paper describes a selective contacting device that is responsive only to sustained frequencies in a discrete narrow band and is insensitive to speech and noise interference. It is of small size suitable for use in a pocket-carried radio receiver and is sufficiently stable to permit 33 discrete resonant frequencies, spaced 15 cycles apart, in less than an octave between 517.5 and 997.5 cycles per second. It has a threshold sensitivity of about 35 microwatts and other operating characteristics that are essential in large capacity systems.

I. INTRODUCTION

Tuned reed selectors used as selective receivers in multifrequency systems involving large numbers of individual selections, such as personal radio signaling,[1] must operate within close and specifiable limits in order to avoid false signaling and to assure satisfactory performance under devious environmental and circuit conditions. In particular, three operating characteristics, or their equivalents, must be controlled, namely: the resonant frequency, the sensitivity (current or power needed at the most sensitive frequency), and the bandwidth (the frequency band in which contacting occurs with an input power twice that needed at the most sensitive frequency).

The permissible variation in these characteristics is much smaller than would seem necessary from first considerations. Resonant frequency changes that seem negligible compared to the frequency spacing between adjacent selectors often become important when other system requirements are considered simultaneously. For example, the frequency range over which contacting will occur depends upon the electrical input level and the selector bandwidth. Consequently, feasible limits for both of these latter quantities must be considered, and in determining allowable frequency deviations from nominal, the lowest probable input level and the narrowest bandwidth must be taken into account. On the other hand, excessively high input levels cannot be allowed even in those unusual instances where conserving power is unimportant, because this necessitates wider channel separations in order to avoid transient operation of adjacent selectors, particularly those having high sensitivities. Furthermore, high input levels result in longer decay times, which often cannot be tolerated. When these and other related factors are considered and the widest manufacturing tolerances are sought, it is found that the above three selector characteristics are closely interrelated, and one cannot be relaxed without making one or both of the others more stringent.

The tuned reed selectors described in this paper have factory adjustment provisions and sufficient structural stability to control in a practical manner the resonant frequencies, the sensitivities and the bandwidths within adequate and compatible limits. As a result, it is feasible to use 33 discrete resonant frequencies, 15 cycles apart, in less than an octave between 517.5 and 997.5 cycles. An available electrical power of 35 microwatts at each individual resonant frequency will just operate the contact, and a power of 100 microwatts will close the contact to a low resistance over 20 per cent or more of the reed period. These and other capabilities to be described distinguish these selectors from many others that are not adequate for reliable operation in large systems.

II. GENERAL DESCRIPTION

Fig. 1 is a photograph showing one complete reed selector with the outside shell removed. Fig. 2 is a partially exploded view showing the subassemblies and indicating how the parts are fitted together. The shell is formed from permalloy sheet; it serves as an effective shield from extraneous fields and as a high-permeability flux path for the internal magnetic circuit. All parts are electrically insulated from the shell. The complete selector weighs about 8 grams.

As shown in these photographs, a tuning fork formed from two reeds brazed to a base block serves as the resonant element. This balanced type of structure does not require a massive support as would a single cantilever reed in order to isolate it from extraneous influences, an important matter for a miniature device. This fork is freely supported within the shell by a compliant frame that further isolates any small residual vibration of the fork base from the rest of the selector, and yet is sufficiently stable to permit the vibrating contact on the end of the tuning-fork tine to be precisely positioned with respect to the stationary contact. This latter contact is carried by a loop of wire spot-welded to a rotatable stud that fits into a tapered hole in an insulating bushing in

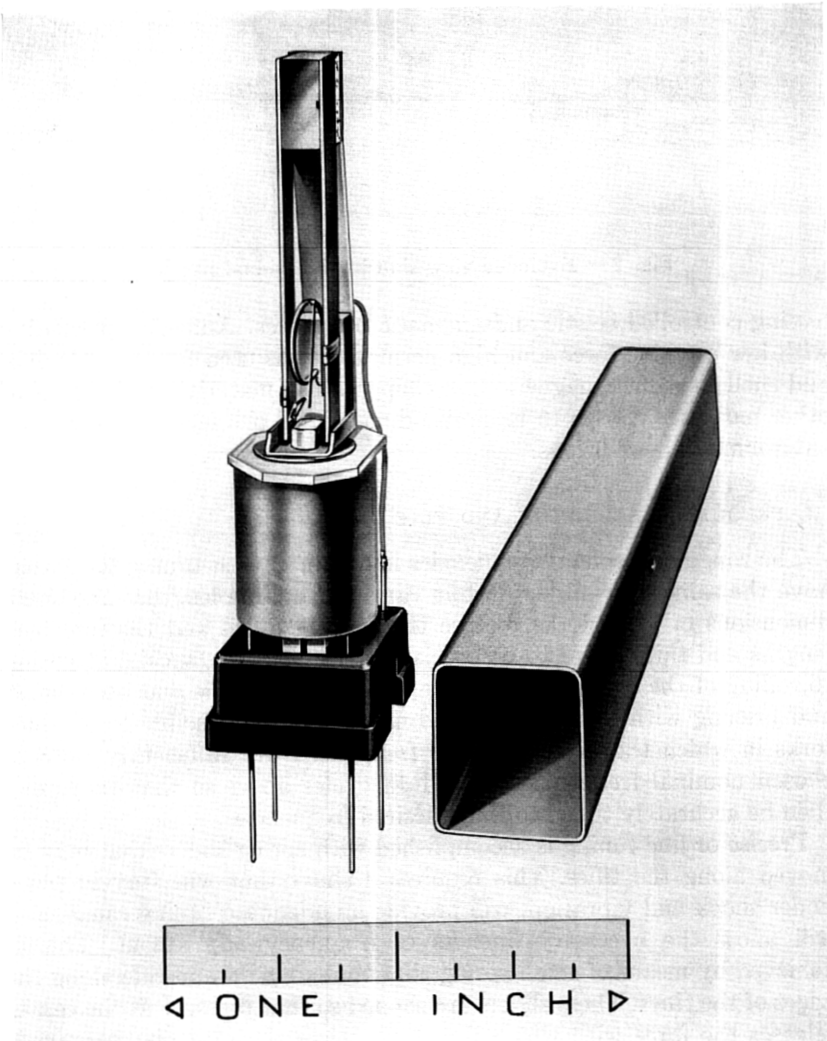

Fig. 1 — Tuned reed selector with shell removed.

the frame between the tines. A magnetic polepiece is positioned between the open ends of the tines, forming two equal gaps. Polarizing magnetic flux is set up in these gaps by a small permanent magnet attached to the opposite end of the polepiece. The energizing coil surrounds the center portion of the polepiece.

The tuning fork is made of a nickel-iron-molybdenum alloy[2] (vibralloy)

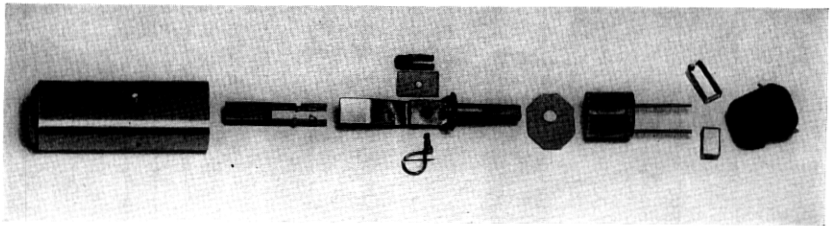

Fig. 2 — Exploded view showing individual parts.

having controlled elastic and magnetic properties. Annealed permalloy with low coercive force and high permeability is used for the polepiece and shell to reduce magnetic flux changes. The materials and shapes of other parts are chosen to minimize dimensional changes with time and environmental conditions.

III. FREQUENCY SELECTION AND FINE TUNING

The range of resonant frequencies is obtained with tuning forks that have the same over-all length but varying free tine lengths. The small dimensions of these forks require the brazing fillets and the free reed lengths and thicknesses to be precisely controlled. By special attention to rolling of the reed stock, precise jigging of the reeds and base block, and brazing with minimum fillet dimensions, it is feasible to produce forks in which the individual tine frequencies are sufficiently close to chosen nominal frequencies spaced 15 cycles apart so that they may then be accurately tuned to these desired frequencies.

Precise or fine tuning is accomplished with spring sliders that may be moved along the tines. This requires a slider that will stay in place under shock and vibration, will provide an adequate tuning range, and will allow the necessary fineness of frequency adjustment. This is achieved by means of small spring clips that snap on and ride along the edges of the tines. These sliders are shaped so that pressure at the center releases the force with which the slider seizes the reed and permits it to be moved. Each slider has a mass of about 1 milligram and provides a tuning range of about 10 cycles on forks near 500 cycles and of about 25 cycles on forks near 1000 cycles. The sliders may be moved in increments less than a thousandth of an inch, permitting the resonant frequencies to be readily set to a desired value within ± 0.05 cycle. The seizure forces are large so that shock and vibration acceleration in excess of 1500 G are required to move the sliders.

IV. CONTACT FACILITY AND SENSITIVITY ADJUSTMENT

The sensitivity is adjusted in manufacture by changing the contact gap separation. A fine rhodium wire having a resonance frequency above the frequency range of the tuning forks is supported by a loop of larger wire that may be rotated on a tapered stud through the frame. The fine wire is pretensioned with a prescribed force against the loop wire to form a lift-off type of contact that is accurately positioned and will follow large tine excursions without objectionable interference with the tine motion. This construction[3] results in a contact that makes to a low resistance with the vibrating contact on the reed for intervals of time that may be 25 per cent or more of the reed period, depending on the applied power. The operating sensitivity of the selector is precisely set by rotating the loop on the stud axis and thereby causing the end of the contact wire to move toward or away from the reed contact. The point of contact is close to the axis of rotation so that a fine control of the contact gap may be achieved.

Bandwidth Control

The bandwidth or sharpness of the resonance curve is determined primarily by three dissipative factors, namely: internal frictional losses in the reed material, viscous losses in the air surrounding the reeds, and eddy-current losses in electrically conducting parts. The last factor has been chosen as the adjustment or control means for bandwidth. A copper washer is placed around the polepiece and where flux changes due to motion of the reeds induce eddy currents in the copper. By selecting the proper washer thickness and diameter and by setting the magnet strength to yield the proper flux density, eddy currents are developed when the tines vibrate that absorb energy and reflect into the system as an effective mechanical resistance that broadens the resonance curve by the desired amount.

V. VIBRATING SYSTEM PARAMETERS

Tabulated in Table I are some measured and derived data that show the magnitudes of the more important vibrating system constants of two selector samples with resonant frequencies nearly an octave apart. These are typical values that will be of interest to those concerned with the vibrational mechanics, electromechanical coupling, and other analytical design factors.

TABLE I

	Nominal Frequency 517.5 cps	Nominal Frequency 997.5 cps
Reed dimensions — length	1.4 cm	1.01 cm
thickness	0.015 cm	0.015 cm
width	0.254 cm	0.254 cm
Effective reed stiffness	1.45×10^5 dynes/cm	3.88×10^5 dynes/cm
Resonant frequency as brazed	560 cps	1068 cps
Resonant frequency with contact	530 cps	1011 cps
Resonant frequency with slider as tuned	517.5 cps	997.5 cps
Effective reed mass as brazed	0.0118 grams	0.0087 grams
Effective reed mass with contact	0.0130 grams	0.0096 grams
Effective reed mass with slider as tuned	0.0138 grams	0.0099 grams
Electrical impedance at resonant frequency	$478 + j231$	$448 + j430$
Electrical blocked impedance at same frequency	$220 + j277$	$235 + j485$
Electrical motional impedance at same frequency	$258 - j46$	$213 - j55$
Current to just close contact	0.275 milliamps	0.275 milliamps
Bandwidth	1.1 cycles	1.3 cycles
Effective mechanical resistance of fork at resonance	0.19 mechanical ohms	0.16 mechanical ohms
Electromechanical coupling factor	$2.24 \times 10^5 \angle 5°$ dynes/abamp	$1.88 \times 10^5 \angle 7.2°$ dynes/abamp
Effective magnetic gap stiffness (each gap — from frequency shift measurements)	-0.02×10^5 dynes/cm	-0.02×10^5 dynes/cm
Corresponding gap flux density	200 gauss	200 gauss
Maximum tine flux density (assuming fringe flux equal to gap flux)	4000 gauss	4000 gauss

VI. PERFORMANCE OBJECTIVES

Consideration of the over-all system operating requirements for personal radio signaling pertaining to such factors as the needed number of individual selections, practical radio receiver power levels, calling rates, and environmental conditions, led to the following objectives for the performance of the reed selectors:

1) Nominal frequency range — 517.5 to 997.5 cycles.

2) Nominal frequency separation — 15 cycles.

3) Frequency deviation limits — ±0.3 cycle, including adjustment tolerances, aging, shock, magnetic changes, and all other instabilities except those due to temperature changes.

4) Temperature-frequency deviation limits — ±0.2 cycle over temperature range of 35°F to 110°F (2°C to 43°C).

5) Nominal bandwidth — 1.0 cycle.

6) Bandwidth deviation limits — 0.8 to 1.4 cycles resulting from temperature changes and all other causes.

7) Nominal current to just operate contact — 0.25 milliamps for a nominal 500-ohm coil impedance at resonance.

8) Just-operate current deviation limits — ±3.0 db resulting from temperature changes and all other causes.

These objectives are mutually consistent in that the limits given in each case are as large as can be tolerated without reducing the limits on some other factor. There are other important design considerations that must not be neglected, such as weight, size and shape, contact life, shock tolerances, corrosion resistance, magnetic interaction and so forth, and with respect to which the selectors must, of course, be adequate. However, the above-tabulated characteristics are the most significant from an operating standpoint and are sufficient under marginal conditions to assure positive operation and avoid false signaling.

VII. TYPICAL MEASURED DATA

Presented below are measured data showing that the above-described reed selector meets these objectives. By means of the spring sliders, the two tine frequencies are made alike within a small fraction of a cycle and are given values that result in a combined fork frequency well within requirements. Attention is given in the assembly and adjustment procedure to magnetically and mechanically stabilize the whole structure. The magnet is stabilized well below its maximum remanence; the whole final assembly is subjected to a moderately high temperature to relieve residual stresses; and the tines are vibrated at a suitable level to bring them into a normalized magnetic state prior to final adjustment. The resulting selectors have resonant frequencies that will remain within ±0.3 cycle from their nominal frequencies at normal room temperatures and under reasonable conditions of mechanical shock and electrical overload. Negligible changes occur under shocks up to 1500 G (2 milliseconds duration) or with input levels 20 db above the just-operate values.

Frequency stability with temperature is achieved by making the forks of a nickel-iron-molybdenum alloy of such a composition that magnetic permeability changes are small and the temperature coefficient of Young's modulus is low and of a magnitude to compensate for dimensional changes with temperature. Operate current stability is realized by additional attention to the design geometry and materials so that changes in temperature cause variations in contact separation that are a small fraction of a mil-inch.

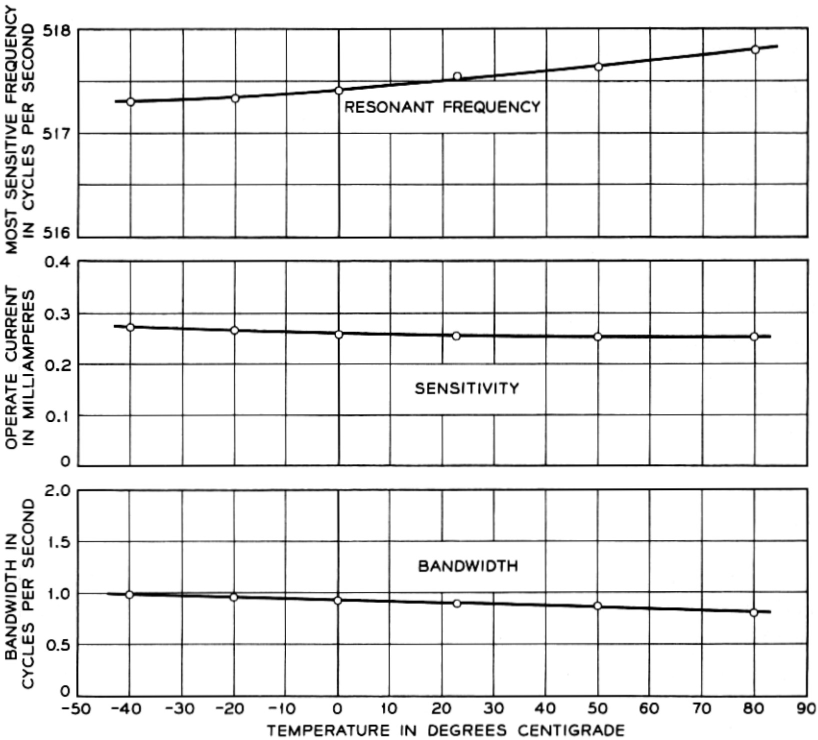

Fig. 3 — Variation with temperature in the operating characteristics of a typical lower-frequency tuned reed selector.

Fig. 3 and Fig. 4 are graphs of measured data showing variations with temperature in the resonance frequency, just-operate current and bandwidth of two typical samples, one at each end of the nominal frequency range. The range covered by these graphs is much wider than that required for most applications. In the more common temperature range of 35° to 110°F, the deviations are well within the limits tabulated above.

Fig. 5 and Fig. 6 are electrical impedance diagrams of the same two selector samples with resistance and reactance as coordinates and frequency as the variable parameter. This form of plot emphasizes the interesting values near resonance and may be used for analytical purposes.[4] From these graphs, it can be determined that the conversion of electrical to effective mechanical power is about 46 per cent and that the available electric power necessary to just operate the contact is about 33 microwatts.

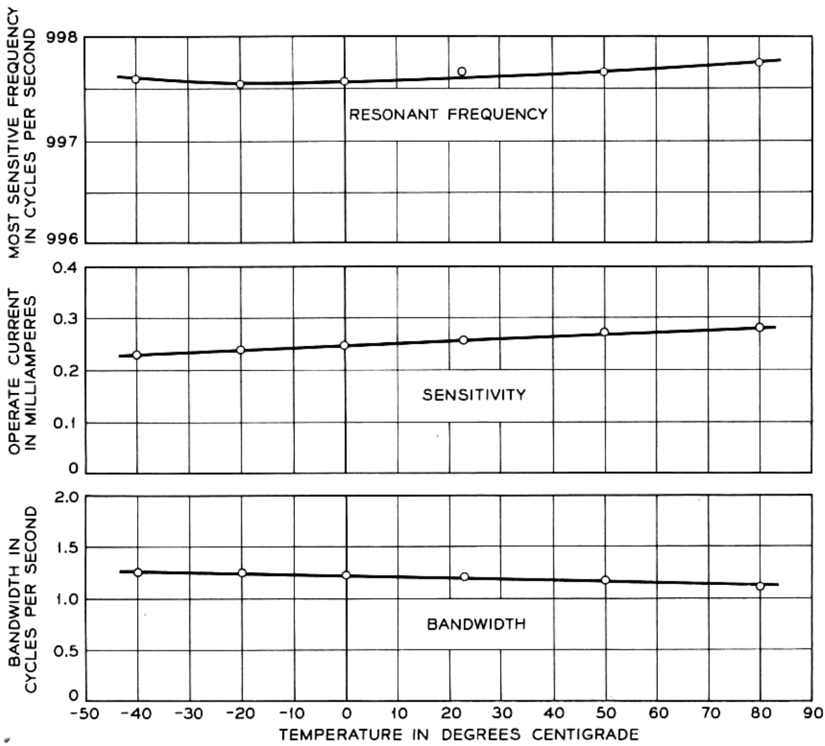

Fig. 4 — Variation with temperature in the operating characteristics of a typical upper-frequency tuned reed selector.

VIII. NOMINAL OPERATING LEVELS AND TIMES

The electrical power source supplying selectors in a system must have an available power capacity sufficient to cause dependable contacting under the worst temperature and adjustment conditions. These worst conditions obtain when the frequency deviation from nominal and the just-operate current are at their maximum values. Considering the limits permitted in these selectors and making allowance for contact quality and life with some statistical advantage taken of the small chance of all limiting conditions occuring simultaneously, it was determined that the minimum electrical input power should be 6 db above that needed to barely close the contact of a nominal selector. At this level, the time required to close the contact after energizing the coil is equal to the time needed for the reed amplitude to decay below contact-

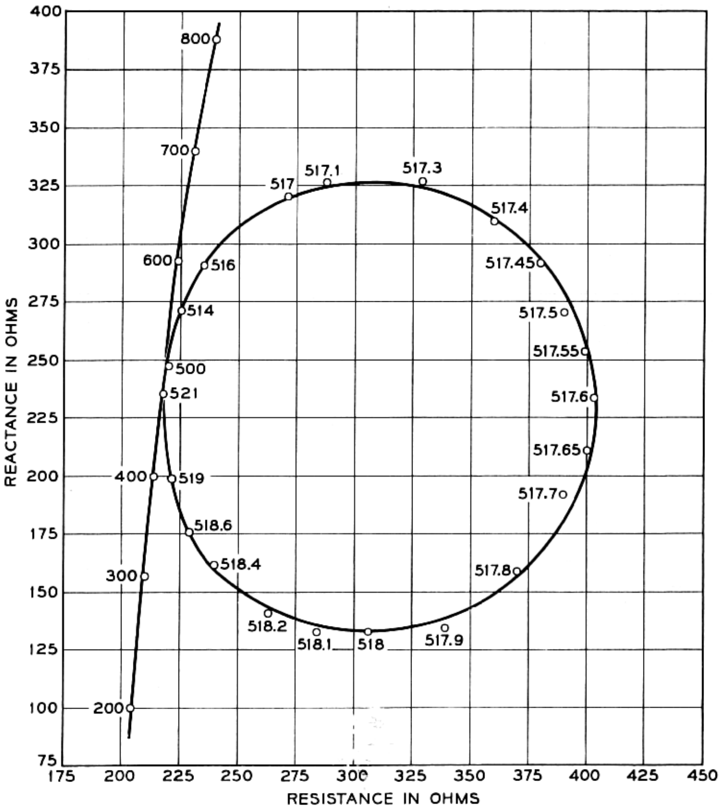

Fig. 5 — Vector impedance diagram of a typical lower-frequency unit.

ing amplitude after the coil current is stopped. For nominal selector constants, this time is approximately 225 milliseconds. Input levels higher than 6 db above just-operate will result in faster operating times and slower decay times, but the sum of the operate and decay times will increase less than 20 per cent up to input levels 12 db above the nominal just-operate value.

IX. CONTACT CAPACITY AND LIFE

The contact has greater capability than would at first seem likely. Such a light contact is most frequently used in circuits to change the potential on a tube or transistor and thereby trigger some desired signaling or switching function without the contact current exceeding a few

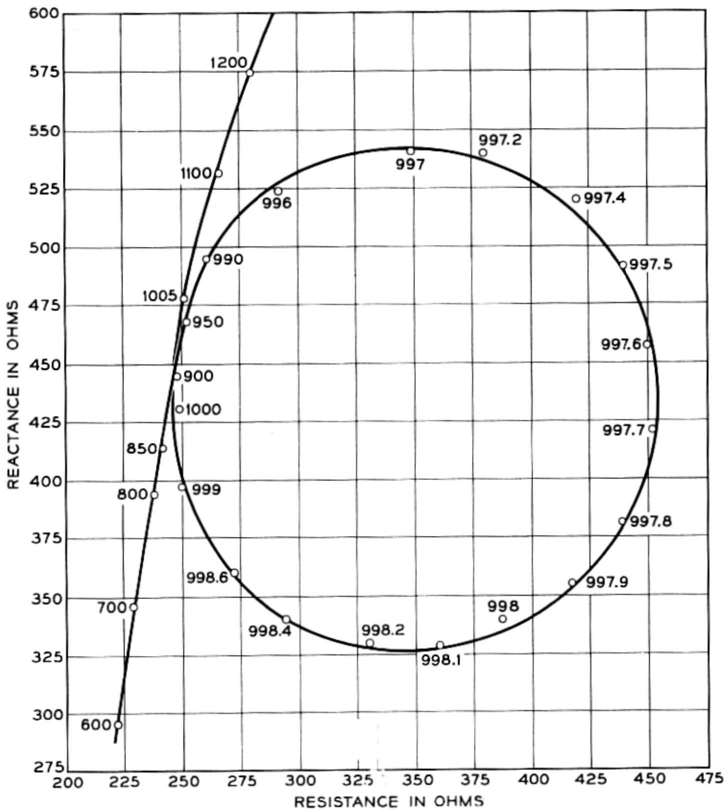

Fig. 6 — Vector impedance diagram of a typical upper-frequency unit.

milliamperes. The contact closure is intermittent at a rate corresponding to the frequency of the selector, and the duration of the individual closures is a small fraction of a millisecond, depending upon the frequency and input level. These short closures, however, occurring at a rate of several hundred times per second, may control current pulses that have an integrated or averaged power that is a substantial fraction of a watt.

The maximum power that can be controlled depends mostly upon the reactive elements in the contact circuit and the life needed from the selector. As an example of what may be expected, Fig. 7 shows changes that occurred in the resonance frequency and the sensitivity of a typical selector when operated continuously (except for a few minutes about every 100 hours during check test) over a period of 1500 hours. The

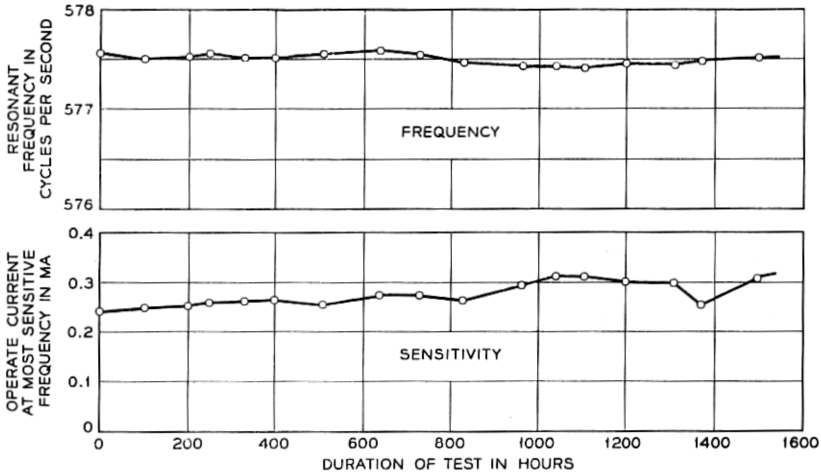

Fig. 7 — Variation with time in the sensitivity and frequency of a selector closing a 12-volt battery through a 240-ohm resistor.

electrical input was 9 db above the just-operate value, and the contact closed a 12-volt battery through a 240-ohm resistor, giving a closure current of 50 milliamperes. Throughout the test period the resonance frequency changed only slightly and the just-operate current increased about 20 per cent. This later change was due to erosion of the contact wire, which increased the contact gap. Erosion was minimized by connecting the fine contact wire to the negative side of the battery. At the end of the test, the diameter of the contact wire was approximately half its original value.

X. APPLICATIONS

The manner in which these selectors are used in the circuits of the BELLBOY Personal Radio Signaling system will be described in a paper to be published on the pocket radio receiver. In this system, three tuned reed selectors are operated simultaneously in the receiver, and these trigger a transistor oscillator that gives an audible signal. The power controlled by the contacts in this case is small.

The substantial power capacity of the contacts can be used to operate relays and other devices directly. Pulses of current from a battery at the selector frequency can be supplied to a smoothing or integrating capacitor, and the relatively constant voltage across the capacitor can be used to operate a sensitive dc relay. The battery may be at the loca-

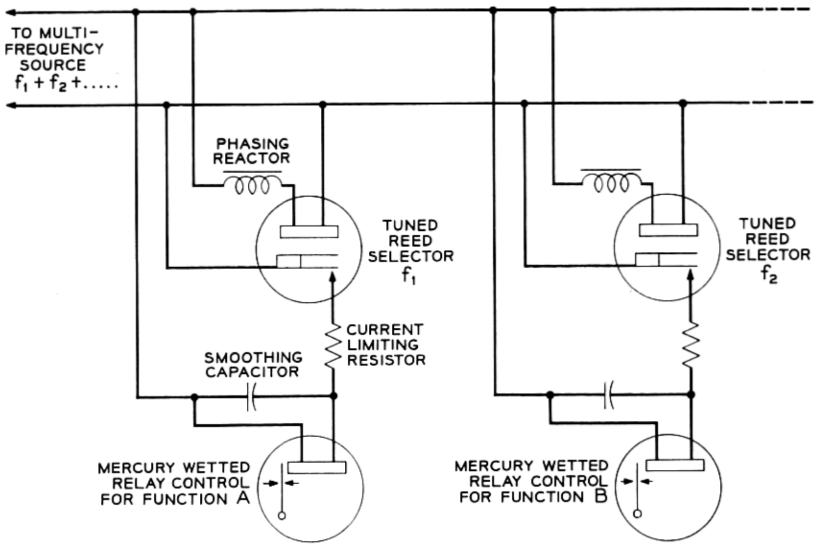

Fig. 8 — Reed selector actuated mercury relay for selective control of multiple functions requiring substantial powers.

tion of the reed selector or may be supplied by superposition over the same circuit used to transmit the selector frequency.

The contact may also be used as a synchronous rectifying means to generate dc from the same ac source that operates the selector, as shown in Fig. 8. When the source frequency corresponds to that of the reed selector, the contact of the selector closes in synchronism once each cycle to send unidirectional pulses to the capacitor and relay in parallel. The capacitor smoothes the pulses and gives a nearly constant current in the relay winding. For maximum sensitivity it is desirable that the contact closures occur near the peaks of the supply voltage wave, and this is accomplished by connecting a large reactance (either inductive or capacitative) in series with the selector winding. This reactance also serves to attenuate the supply voltage applied to the selector winding to avoid overdriving the reeds, because a supply voltage large enough to operate a relay is ordinarily many times that needed to operate the reed selector. Combination circuits using reed selectors and mercury-wetted contact relays provide a simple means of selectively controlling substantial powers to perform a multiplicity of functions over a single pair of wires.

When operated just below the contacting level, these selectors have a

Q (resonant frequency-to-bandwidth ratio) in the range of 500 to 1000 and therefore may be used effectively in a selective bridge or filter circuit as described in a previous paper.[5] The use of such a selective circuit in the feedback loop of a single transistor oscillator results in an attractively simple source of frequency having a precision corresponding to that of the selector.

XI. ACKNOWLEDGMENTS

Original suggestions regarding the construction of this selector and skilled model work were contributed by the late R. L. Guncelle. Essential refinements in the design and in the fabrication techniques were made by K. F. Bradford and D. H. Wenny. E. J. Kasello carried out most of the adjusting and testing. The successful outcome of this development is due in no small measure to their efforts.

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