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21st June, 1947.

Dear Sir Krishnan,

I am writing this in continuation of my letter of 12th June which I sent to your address at Delhi.

Herewith a suggestion in the accompanying note which you may perhaps like to consider for the detection of capacity changes of the order of 0.001 mmf. The underlying principle is essentially simple. The apparatus suggested is shown in the form of a block diagram, as I did not want to load it up with the details of the several parts of it; these can be found in any of the standard books on radio engineering or radio frequency measurements. But if a detailed diagram is required, I shall be glad to make one and send you.

If you are likely to try the method, I shall be interested to hear if it works. I need not say that if I can be of any further assistance, you have only to drop me a line.

A few days back AWA Technical Review, Vol. 7, No. 3, 1947, came in; I am sending it on to you under separate cover and invite your attention to the paper "A Radio-frequency Inter electrode-Capacitance Meter" by Lehany and McGuire on page 271. I have not studied it and so am unable to say how far it will be useful to you. Will you please return it after you have done with it?

Wishing you and Mr. Venkatesan the best of success,

Yours sincerely,

K. Sreenivasan.

Enc:- 1.

Sir K.S. Krishnan, D.Sc., F.R.S.,
Professor of Physics,
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KS/VS.

A SUGGESTION FOR DETECTING CHANGES OF CAPACITY OF THE ORDER OF 0.001 MMF.

The problem is to detect a change of the order of 0.001 mmf. in a capacity which may be anywhere between say 20 and 500 mmf. This corresponds to one part in 20,000 to one part in 500,000. Both absolutely and in relation to the total capacity, the change of 0.001 mmf. is very small. Even with rigidly stable power supplies and circuit elements, and using high Q, that is, low resistance tuned circuits, it is doubtful if the resonance method can detect this change whether using a vacuum tube voltmeter or a balanced bridge.

2. THE HETERODYNE METHOD: Perpahs a more hopeful method is to convert the change in capacity to one of frequency, by using the heterodyne principle of two oscillators beating with each other, as for instance, in the beat frequency oscillator so much used nowadays. Mr. Venkatesan himself suggests this and it is worth trying, particularly because the experiment is not one of determining the actual magnitude of the change in capacity as of detecting it and then restoring the capacity to its original value by suitably altering the mixture in the cell.

3. The circuit suggested is, as the block diagram shows, closely similar to that of the beat frequency oscillator. The same principle is used in the frequency deviation monitoring instruments used in radio transmitting stations. If a good beat frequency oscillator is readily available, the preliminary experiment could perhaps be carried out by a slight modification in it; The test will then be only at one frequency, namely, the frequency of the fixed oscillator in the instrument. (See any book on oscillators or high frequency measurements.)

4. CIRCUIT DETAILS: The two oscillators O_1 and O_2 feed into a mixer or detector; at the output of the latter will appear not only the frequencies of the two oscillators, but their sum and difference frequencies as well as others. The low pass filter with a cut off frequency f_c equal, say, to 5 KhZ, allows

only the difference frequency to pass through to the input of the audio frequency amplifier and keeps back all the others. The audio frequency amplifier may consist of either two or three stages, the output stage transformer coupled, and the others resistance-capacity coupled. A pair of telephones or a loudspeaker forms the output circuit of the amplifier.

5. The cell forms a part of the tuning capacity of the self oscillator O_1, which should preferably have two variable air condensers in parallel with the cell, the coarse one of 250 mmf. (max.) capacity and the fine one of 15 or 25 mmf.(max.). The former is for adjusting the frequency within the desired region of say 8,000 to 20,000 KhZ; the fine condenser is for adjusting the frequency of O_1 to that of O_2. The source of modulation can be any audio frequency oscillator provided it has a very pure note for its output; the frequency f_m is preferably 1.0 KhZ. A tube maintained tuning fork oscillator would, if available, be excellent.

6. Oscillator O_2 may be an identical oscillator to O_1. Or it could be a quartz crystal oscillator; in the latter case the measurement can be made ~~conducted~~ only at the frequency of the crystal. Using a number of crystals, spot frequency measurements will be obtained. Measurement at any desired frequency within the band will not be possible. If, however, a good signal generator, such as the one made by the General Radio Coy., of U.S.A. is available, it will include both Oscillator O_2 and the modulation source M; it is extremely convenient, easy to handle, very well shielded and capable of giving an adjustable output at any frequency and with any desired modulation depth.

6. BEFORE THE CRYSTAL IS INTRODUCED INTO THE CELL, if the switch S is open and the two oscillators are adjusted to have exactly the same frequency fo, the output from the mixer will have Zero frequency and therefore Zero magnitude. In other words, there will be no sound in the telephones. But with the

switch S on and the two oscillators still exactly of the same frequency, there will be an output in the mixer and so a sound in the telephones of frequency f_m

8. WHEN THE CRYSTAL IS INTRODUCED INTO THE CELL, the frequency of the oscillator O_1 will undergo immediately a change from f_o to $f_o \pm df$. (At the input terminals of the detector, there will now be (a) the voltage of frequency $f_o \pm df$) from the oscillator O_1 and (b) the voltage of frequency ~~xxxx~~ f_o from Oscillator O_2 modulated at a frequency f_m if the switch S is on, but without the modulation if S is not on.

9. If S is not on, the output from the mixer will have a frequency df, equal to the difference in the frequencies of the two oscillators. If df is appreciable and audible, it will be heard on the loudspeaker. The cell mixture can then be altered suitably to reduce the frequency of the note back to Zero as it used to be before the crystal was introduced into the cell.

10. If, however, the change df in the frequency of the oscillator O_1 is in the sub-audio range, the oscillator O_2 must be modulated by putting on the switch S. The input into the detector will then consist of the frequency $f_o \pm df$ from oscillator O_1, and the frequency fo from oscillator O_2, but carrying the modulation f_m. The output from the audio frequency amplifier will then be a note of frequency f_m, but modulated at the frequency df. If df is of the order of a few cycles per second, the note fm will have a beat of df on it. The waxing and waning of the sound will be found to be unmistakable. The cell mixture is then adjusted as usual till the beat on f_m due to df ~~on f_m~~ disappears and the pure note f_m alone remains.

11, If df is, however, not small, the sound in the telephones will be rather confusing; this is due to the beating of f_m and df, and these again beating with each other and with f_m. Here again these sounds will resolve and disappear leaving the clean note f_m when the cell mixture is adjusted.

12. The modulation of oscillator O_2 is essential when df is

small and in the sub audio range. This case is likely to arise when f_o is low, of the order of 500 KhZ. If however df is high, the modulation of oscillator O_2 is both unnecessary and undesirable. A few examples have been worked out in the table below taking representative values normally used in practice. They are merely illustrative and may be changed to other values, within the usual limits.

13. A WIEN'S BRIDGE may be used to measure the frequency of the output of the audio amplifier, but it does not seem very necessary at first sight. And when df is of the order of a few cycles, it can hardly be useful. In any case, the exact value of the frequency change is not required to be measured.

14. A DISCRIMINATOR may, at a later stage, be considered at the output of the audio amplifier, as it will be useful for all values of df. The modulation fm will then be necessary. The discriminator circuit suggested here is similar to what is used in frequency modulation receivers and for automatic frequency control in the ordinary type of super heterodyne receivers. (See for example chapter 20, pages 180-2 of the Radio Designer's Handbook by Langford Smith).

15. It has already been suggested that a good signal generator with provision for either external or internal modulation can be used for oscillator O_2. The General Radio Company instrument is one of the best. If this is not available, a quartz crystal controlled oscillator using a good crystal of low temperature coefficient of frequency may be tried. The frequency of such an oscillator may be so stable when compared with that of the self oscillator O_1 that it may prove more a hindrance than a help. It would be best if the two oscillators change their frequencies similarly with regard to temperature, supply voltages etc. Temperature control is best avoided as far as possible. It takes space and involves trouble and expense.

16. At least in the beginning, separate supplies are advantageous,

one for the oscillator O_1, another for the oscillator O_2, (unless a signal generator is used), and a third for the rest of the apparatus. Well charged accumulator batteries of ample ampere hour capacities are to be preferred to a.c.mains supply units. Mains noises, hum etc., can be troublesome. Normally, it should not be necessary to wait for one and two hours after the supplies have been switched on.

17. To avoid, or, at least, to minimise frequency changes due to changes in temperature, supply voltages etc., the measurement should be carried out quickly, in the space of a few minutes. During this time, it is not very likely that changes in frequency in the set itself will be comparable to that caused by introducing the crystal into the mixture. In any case the latter must be arranged to be more than the former. The change in frequency due to the crystal in the cell takes place suddenly, whereas the other is in the nature of a drift.

18. The two oscillators must be thoroughly screened from each other; otherwise they will "pull" each other into synchronism and there will be a "silent zone" on the condenser. This is a familiar phenomenon.

19 LIKELY VALUES OF df FOR A CAPACITY CHANGE OF 0.001 mmf: These are obtained very simply from the standard formula for the resonant frequency of an L.C. circuit.

(a) Before the crystal is introduced the oscillator O_1 has the frequency $f_o = \frac{1}{2\pi\sqrt{LC}}$ where L and C are the inductance and capacity of the resonant circuit, including the cell.

(b) After the crystal is introduced, the frequency changes from f_o to $f_o \pm df$ because of the change in the capacity from c to $c \mp dc$, where $dc = 0.001$ mmf, say,

$$f_o \pm df = \frac{1}{2\pi\sqrt{L(C \mp dc)}} .$$

To a first order of approximation,

$$df = f_o \frac{dc}{2c}.$$

In the table below dc is taken as 0.001 mmf; the values of C are representative of those used, for example, in a radio receiver. The values of L vary accordingly.

f_0 (KhZ).	C (mmf).	dc (mmf)	df (cycles per second).
500	500	0.001	0.5
,,	250	,,	1.0
1000	200	,,	2.5
5000	100	,,	25.0
10000	50	,,	100.0
20000	20	,,	500.0

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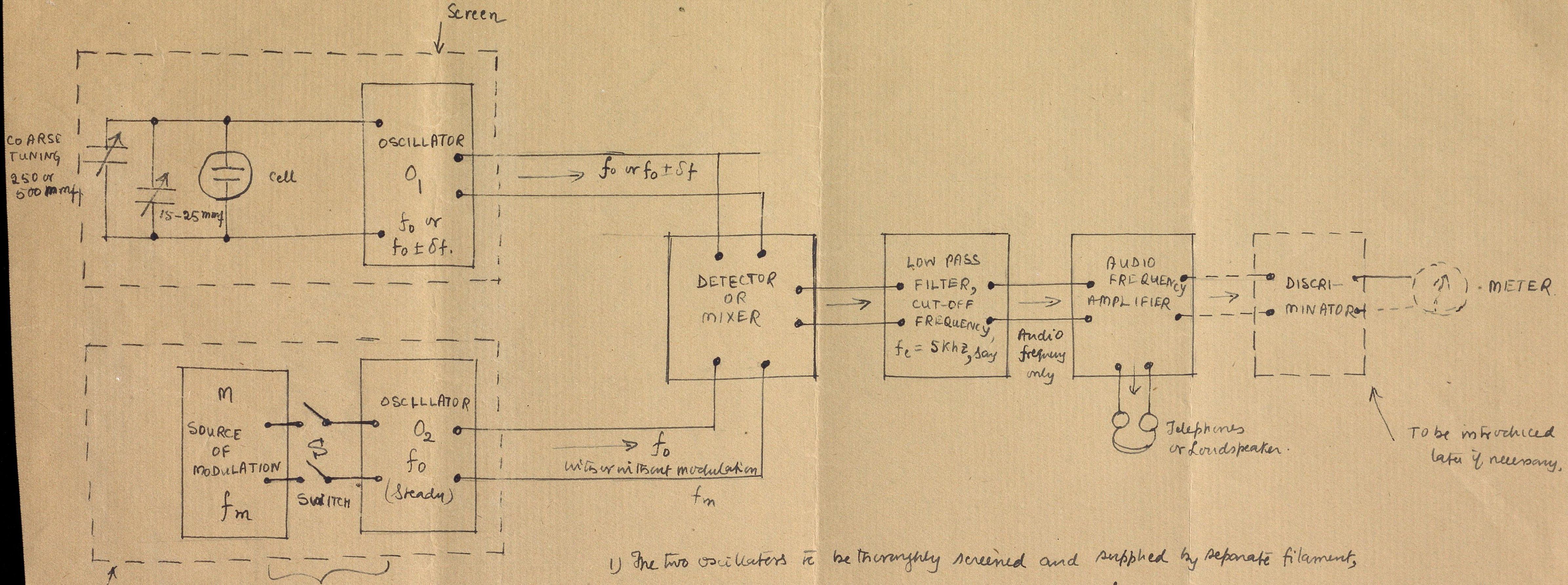

To be introduced later if necessary.

Screen.

Any standard Signal generator of a good type will take the place of these two.

1) The two oscillators to be thoroughly screened and supplied by separate filament, anode and grid batteries. Use shielded leads wherever necessary.

2) Keep away a.c. power supply leads from the neighbourhood of the apparatus Otherwise there will be a 50 cycle modulation and this may cause confusion.