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SOLID STATE AUDIO FREQUENCY SPECTRUM SHIFTER

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An Audio Frequency Spectrum Shifter is a device, which is capable of changing the frequencies of the entire audio spectrum by the same predetermined amount. By this change a harmonic overtone structure will be altered, the relationship of the overtones will become non-harmonic, and new sounds will evolve.

Therefore, a frequency spectrum shifter is not a transposing device, but rather in its musical application a tool for the generation of new tonal effects.

For a very special application audio frequency spectrum shifters have been used for some time. It has been found, that shifting speech frequencies by a small amount, say 5 Hz, reduces the acoustical feedback in a P. A. system. The devices developed and built for this purpose, have been tailored for and are limited to speech frequencies, for which they perform satisfactory, 1) 2).

Furthermore a multiple single sideband device for music frequencies has been developed to simulate the Choral Tone Effect, 3).

Finally an apparatus for large changes of musical frequencies known under the name "Klangumwandler" is in use in the German broadcasting system, 4). This device operates through double heterodyning and single sideband production by filtering. To a certain extent this apparatus is related to the device, which will be described in this paper, except for the inclusion of the phase shifter SSB production in the new Spectrum Shifter.

Evidently selective single sideband generation by filtering is very expensive. If not extremely steep filters are employed, the rejection of the low frequencies of the unwanted sideband will not be satisfactory. It is reported, that the unwanted sideband rejection of the German device becomes less than 30 db at audio frequencies as low as 40 Hz.

In view of this problem the single sideband production by the phase shifter approach was analyzed, before freezing on a new concept for the overall system. At low frequencies this approach proves superior. At higher frequencies, however, the band pass filter solution is better.

In order to secure the advantages of both approaches and to achieve the optimum performance at a given expense, an apparatus was built, which combines both techniques.

The Subassemblies of the System and their Basic Functions.

Fig. 1 shows a block schematic diagram of the new spectrum shifter. The program material received at the input terminals is fed to two phase shifters (phase filters No. 1 and No. 2) also known as Dome filters, [2], which process the spectrum from 40 Hz to 10,000 Hz so that the phase difference between the 2 outputs is 90° for all frequencies of the indicated range.

These phase shifted frequencies are then received at one set of inputs of the balanced modulators M_1 and M_2. The second inputs of these modulators are connected to the outputs of phase filters No. 3 and No. 4, which supply the oscillator frequency of 20 KHz 90° apart in phase.

The 20 KHz oscillator generates a square wave, the upper partials of which are attenuated by a 20 KHz cutoff low pass filter. This approach in contrast to the tank circuit "purified" crystal oscillator has been chosen, since it is not vulnerable to the drift of an L-C tuned circuit.

The mixer outputs are connected to a balancing potentiometer, which is adjusted for the suppression of one of the sidebands of the heterodyned program signal. Depending upon which of the filter outputs (No. 3 or No. 4) is connected to M_1 and which one to M_2, the upper or the lower sideband will be suppressed.

In the frequency spectrum shifter described here the lower sideband is being attenuated in order to be compatible with the single sideband filter (SSB following the amplifier A_1), which also suppresses the lower sideband, [1]. Thus the sideband attenuation by the phase filters is enhanced by the sideband attenuation of the single sideband filter.

M_1 and M_2 are balanced modulators, so that the carrier is suppressed, which is imperative for the undisturbed performance of the device.

The output of the single sideband filter is connected to one input of the balanced modulator M_3. The other input of this modulator receives a variable oscillator frequency in the total range of 15 KHz to 25 KHz. Again, two sidebands appear at the output of M_3, one of them being in the audio range and representing the shifted frequency spectrum, and the other being in the ultrasonic range. The latter portion is suppressed by the low pass filter before reaching the output terminals through the output amplifier A_2.

The Single Sideband Generation by the Phase Filter Approach.

Since this spectrum shifter deviates from the single sideband filter device described by D.J. Mac Lean and A.J. Prestigiacomo by the inclusion of the phase shifter principle, a brief description of this approach (which is related to one of the known R.F.methods) will be in place.

Fig. 2a shows 4 tracks of a sine wave at phase angles of 0°, 90°, 180°, and 270° relative to the first track and with the associated wavelength λ_1. If by smooth transitions first the 0° portion is derived, then the 90° portion, the 180° portion, the 270° portion and so forth, a new wavetrack evolves, which is presented in Fig. 2b. This new wavetrack has the wavelength λ_2, and in this case a lower frequency. The scanning can also take place in a reverse order, which would increase the original frequency.

It will be recognized, that at each "revolution" of the scanner (which may be inductive, capacitive or electronic), the output frequency will be either increased or decreased by one cycle depending on the rotational direction.

An inductive (mechanically rotating) scanner of this type has been described in a 1962 paper by Mahlon D. Burkhard, 2). This device is used for a relatively low frequency shift (around 5 Hz). An electronically switched scanner with a range of low shifting frequencies and with 3 wavetracks 120° apart has been developed by the Baldwin Company, 3). Naturally, electronic switching (scanning) would have to be preferred over mechanical scanning, if large frequency shifts (in the order of 20,000 Hz) are desired.

From the presentation in Fig. 1 it will be noted, that only 2 and not 4 signals each with a phase difference of 90° are available. However, since balanced modulators are symmetrical devices, the 180° and 270° signals are produced automatically.

The Combination of the Phase Shifter and Band Pass Filter Approach.

In order to further clarify the performance of the overall frequency spectrum shifter, the processing of a typical sound is demonstrated through Fig. 3.

In a linear scale Fig. 3a shows 5 frequencies (300, 600, 900, 1,200, and 1,500 Hz) which are harmonically related to each other. At the potentiometer (Fig. 1) following the outputs of the modulators M_1 and M_2 a spectrum is obtained, which is presented in Fig. 3b. Here the carrier of 20 KHz is suppressed and also the frequencies of the lower sideband. Fig. 3c shows a further suppression of the lower sideband by the single sideband filter. This spectrum is obtained at the output of the filter SSB.

Finally, by impressing an oscillator frequency of 19,500 Hz upon the modulator M_3, a frequency spectrum according to Fig. 3d results, all the partials of which are now shifted up by 500 Hz compared with the original spectrum. Evidently the original harmonic relationship does not exist any more.

Further changes of the overtone structure are illustrated through the graph of Fig. 4. It will be of special interest, that in a down shift the partials go through zero frequency one at a time, and that at a detuning by a sufficient amount the original spectrum will be inverted, which will lead to many interesting and new sounds.

Circuit Details and Layout of the Spectrum Shifter.

Circuit details of the device, the basic subassemblies of which were shown in Fig. 1, are presented in Fig. 5. The Dome filters between the input and the modulators M_1 and M_2 are of the same kind as described in Mahlon D. Burkhard's paper on a "Simplified Frequency Shifter for Improving Acoustic Feedback Stability".

The balanced modulators (in their electronic version) may be ring modulators or beam deflection tube balanced modulators to name two kinds. The crystal oscillator used for this device as well as the single sideband filter is of a proven design (see the paper by Prestigiacomo and Mac Lean).

The L-C oscillator for this device is a special development with high frequency stability obtained by proper matching of a high Q tank circuit to the transistor circuitry and by automatic amplitude control with a lamp in one output branch of a phase splitter (Q18). The positive feedback voltage obtained at the collector of this transistor is counteracted by a negative feedback voltage from the emitter, which rises, when the lamp resistance increases by heating up due to an A.C. voltage rise at the base.

The further details of this schematic diagram including the balanced modulator M_3, the low pass filter and the output amplifier should be self explanatory.

Finally, Fig. 6 shows the layout of the components and sub-assemblies on the chassis of the device, which has been built for The Electronic Music Center of Columbia and Princeton Universities. This apparatus has been designed with a 19" x 3 1/2" front panel for standard rack mounting and is completely self contained. The controls include those for modulator balancing and range switching. The input is high impedance and transformer coupled to facilitate ground separation. The output is low impedance and transformer coupled for the same purpose.

Due to the combination of the phase shifter and the single sideband techniques in the described device the unwanted sideband rejection is appr. 43 db at 40 Hz and around 80 db at 1 KHz.

In closing I want to extend my thanks to Mr. Mahlon D. Burkhard and to Mr. Mac Lean, who gave me valuable information. Very special thanks I owe Professor Vladimir Ussachevsky of Columbia University, through whose initiative this development was made possible.

References.

1.- A. J. Prestigiacomo and D. J. Mac Lean, "A Frequency Shifter for Improving Acoustic Feedback Stability," Thirteenth Annual AES Convention, October, 1961,
see also: M. R. Schroeder, "Improvement of Acoustic Feedback Stability in Public Address Systems," Proceedings of the Third International Congress on Acoustics, 1959, v. 2, p. 771.

2.- M. D. Burkhard, "A Simplified Frequency Shifter For Improving Acoustic Feedback Stability," Fourteenth Annual AES Convention, October, 1962.

3.- The Baldwin Piano Company, Cincinnati, Ohio, U.S.Patent No. 3,004,460, inventor W. C. Wayne, Jr.

4.- Südwestfunk, Baden-Baden, W. Germany, West German Patent No. 1 051 100, inventors Dr.-Ing. Ludwig Heck and Dipl.-Ing. Fred Bürck. See also original article by Dr. L. Heck in the Gravesano Blätter, and Professor Vladimir Ussachevsky: "Musical Timbre By Means Of The 'Klangumwandler'", Tenth Annual AES Convention, Sept. 29-Oct.3, 1958, Preprint No. 65.

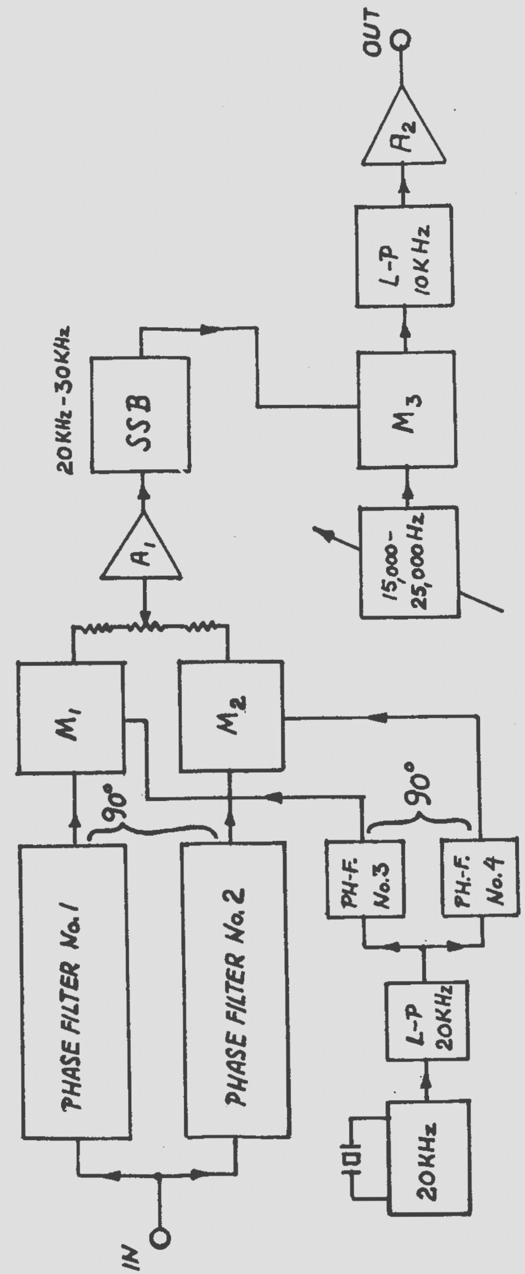

Fig. 1: Block schematic diagram of Frequency Spectrum Shifter.

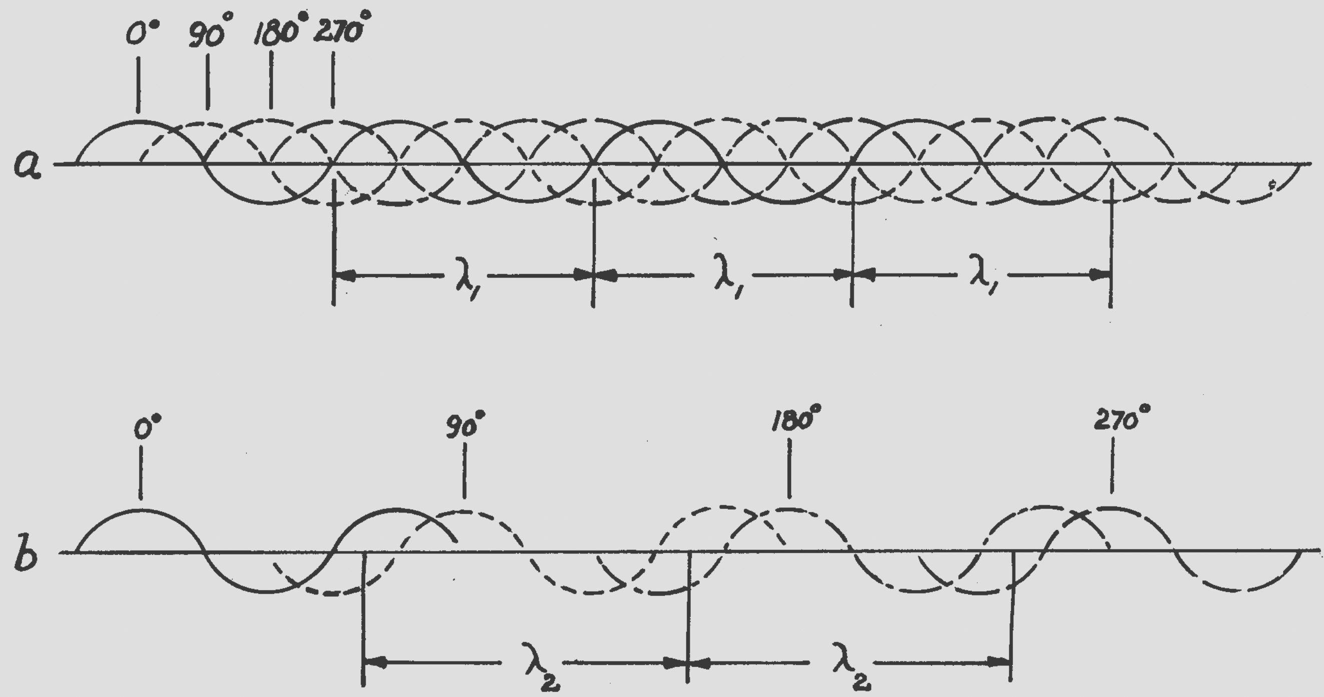

Fig. 2: Single sideband production by phase shifter method; a) 4 wave tracks, 90° apart in phase, generated by phase shifter; b) resultant wave track obtained by scanning of above 4 wave tracks.

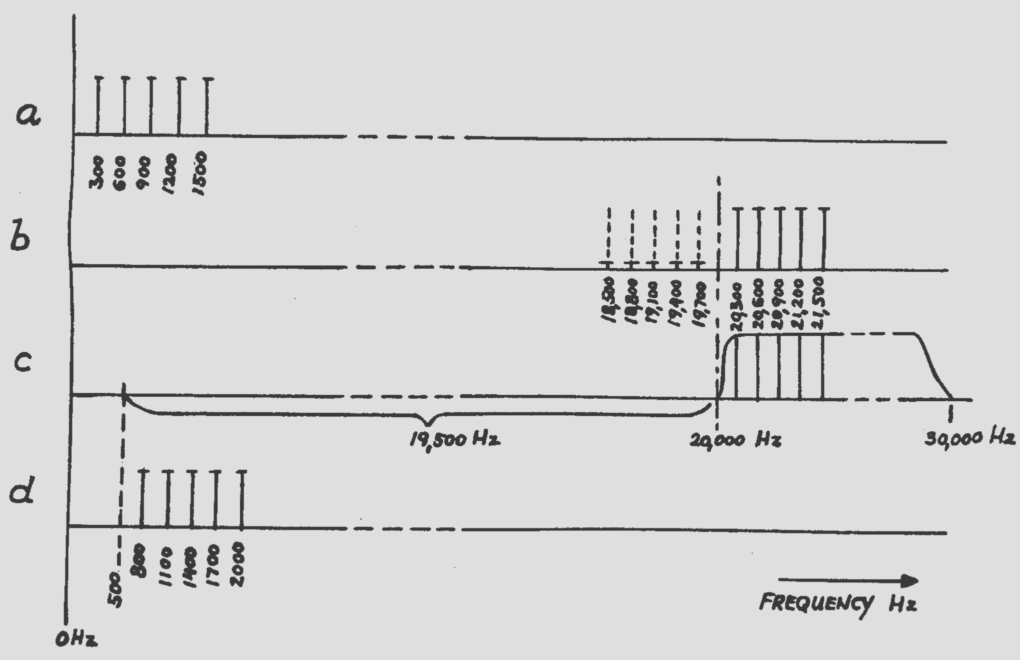

Fig. 3: Frequency conversion by heterodyning, phase shifting, single sideband filtering and re-heterodyning; a) original frequency spectrum; b) converted frequency spectrum by phase filtering and heterodyning; c) converted frequency spectrum after passing single sideband filter; d) re-heterodyned single sideband frequency spectrum.

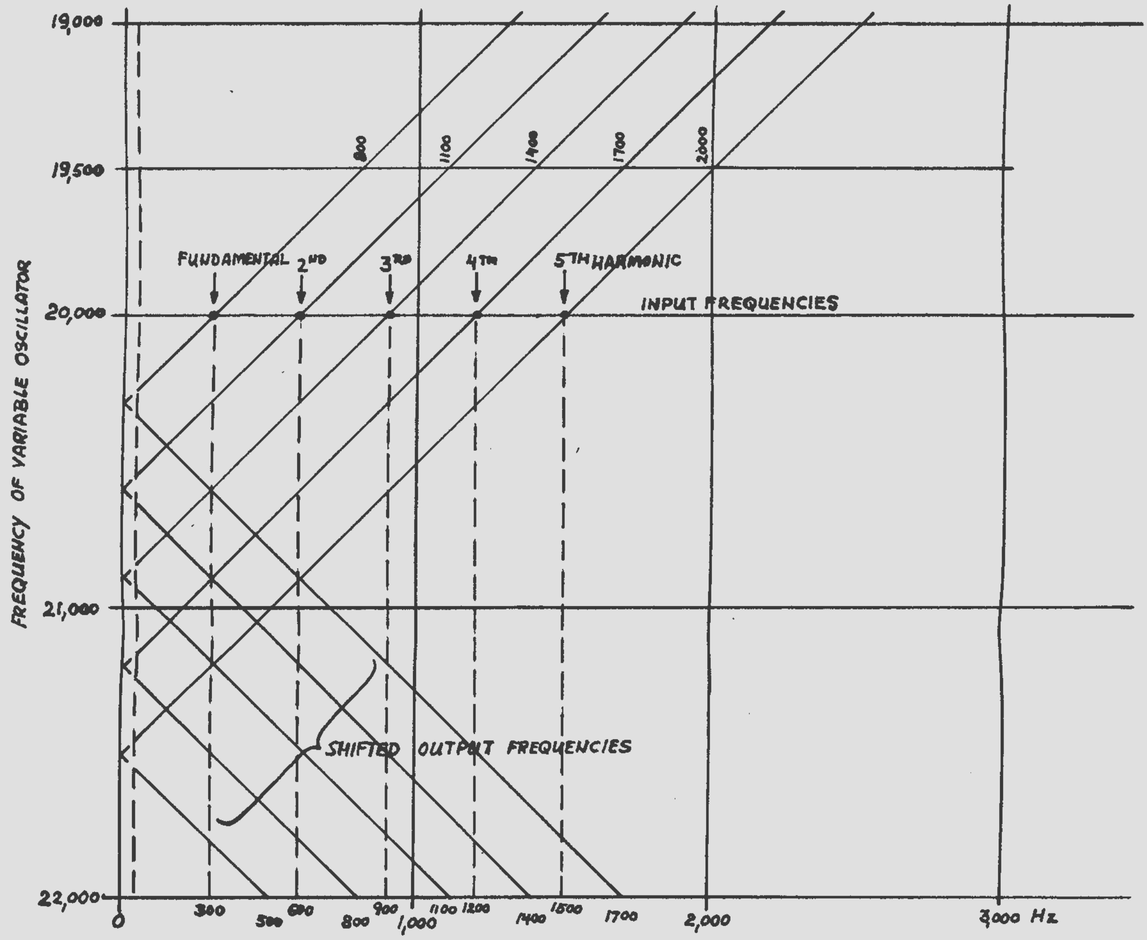

Fig. 4: Change of frequency spectrum as a function of re-heterodyning frequency.

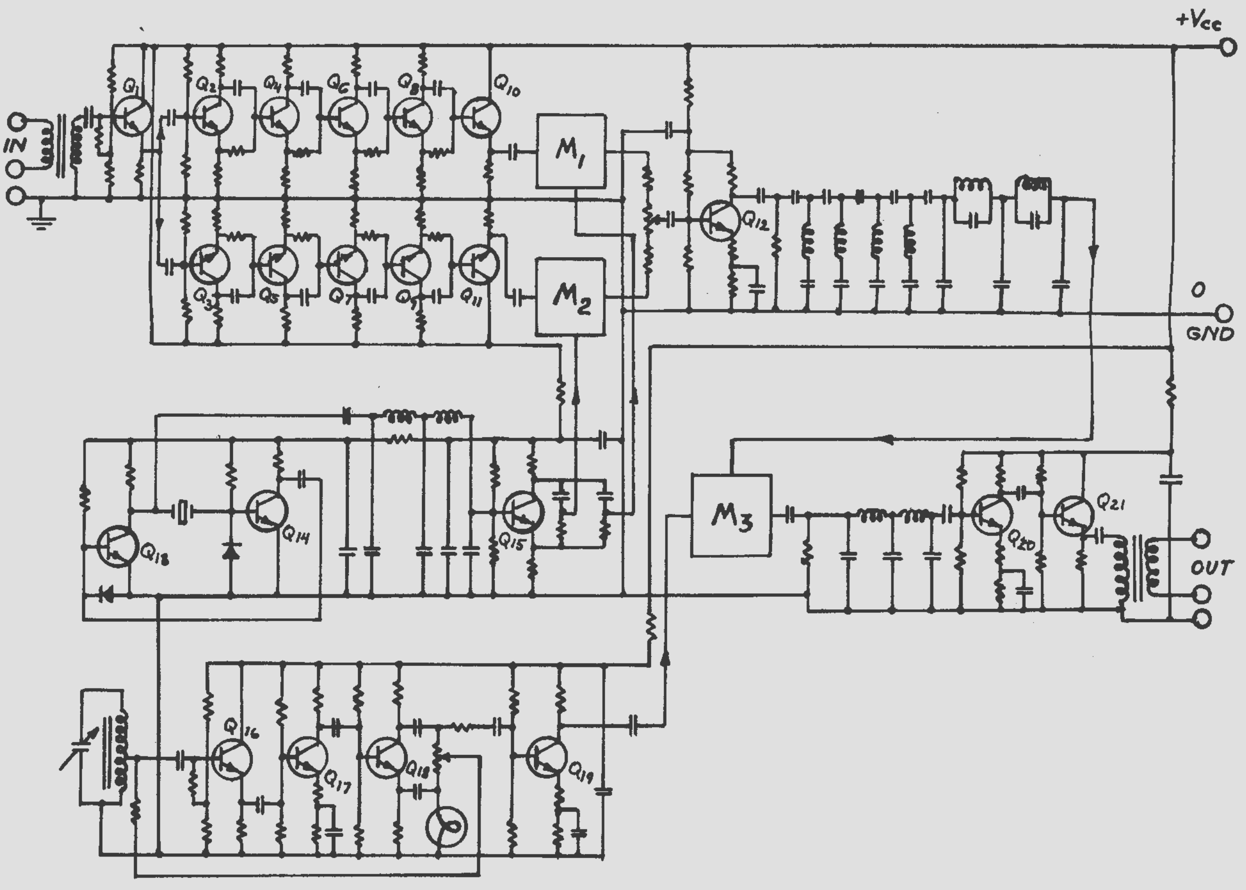

Fig. 5: Complete schematic diagram of Frequency Spectrum Shifter.

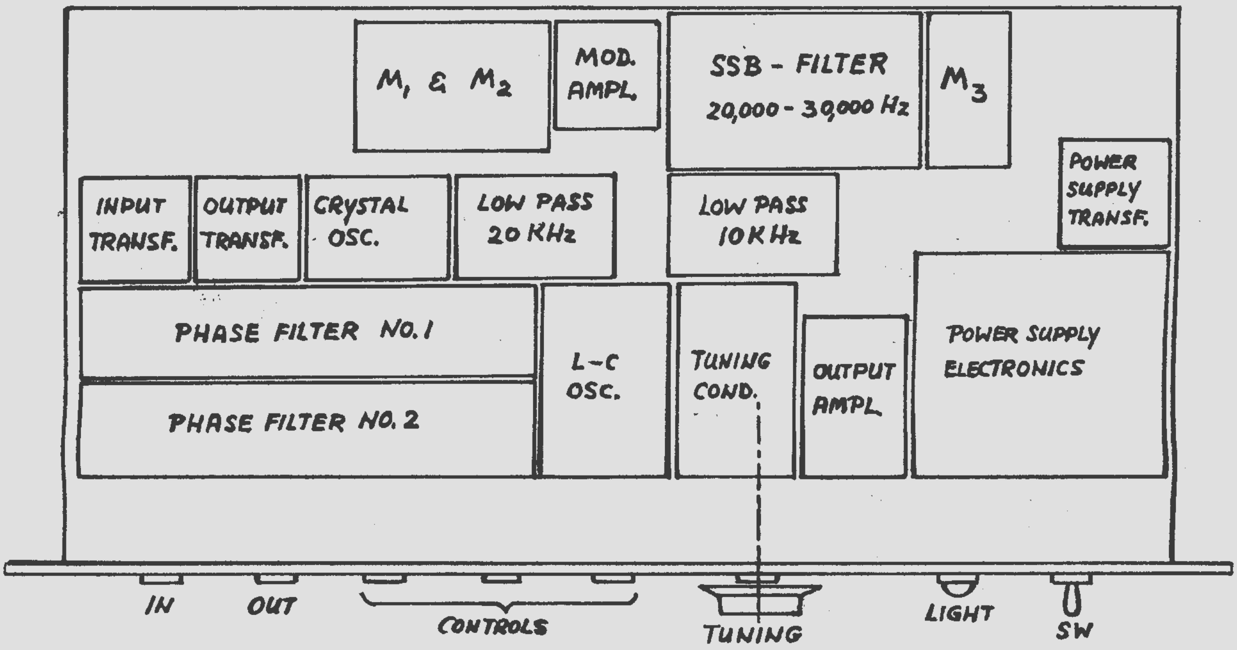

Fig. 6: Layout of subassemblies (top view) of Frequency Spectrum Shifter.