Design of VFT FSK Telegraph and S + Dx System Using Active Filters

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5.0 SPEECH AND VFT FILTER

5.1 Speech Filter

The boundary condition of the Speech filter are defined in CCITT recommendation H 35. (Appendix 3). The Speech filter operates to a channel defined in CCITT G 232.

The parameters defining the boundary conditions are :

(a) The pass band tolerance or ripple
(b) Cut off frequency Ω_c
(c) Minimum rejection in the stop band
(d) Transition band bounded by Ω_c and Ω_s

The design involves :

(a) Selection of transfer function to match the boundary condition.
(b) Realisation of transfer function.
(c) Minimising parameter sensitivity to component changes.

5.2 Typical Transfer Functions

Typical standard functions available are maximally flat, T'Chebychev, T'Chebychev Cauer, Elliptic functions etc. All these functions are synthesised from the basic biquadratic section. Typical Biquadratic Equation may be expressed as follows :

$$\frac{(a_1 p^2 + b_1 p + c_1)}{a_2 p^2 + b_2 p + c_2}$$

Such biquadratic function in general have two poles and two zeroes.

5.3 Particular types of biquad functions of interest are shown below with their respective frequency response curves.

Case I

5.3.1 (a) When $b_1 = 0$,
The function yields a conjugate pair of zeros and complex conjugate pair of poles as depicted in figures.

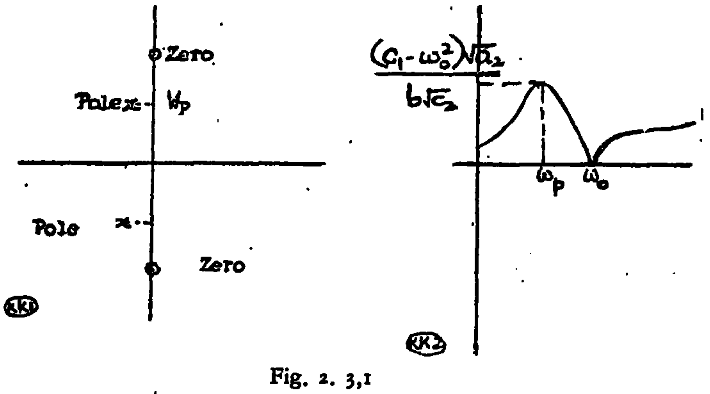


Fig. 2. 3,1

Case II.

5.3.2 $C_1 = 0$ and $a_1 = 0$.

Such a biquad function will have its zero at the origin and the poles will be complex.

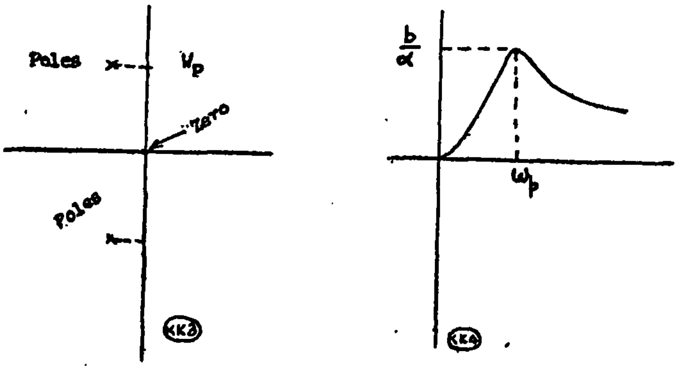
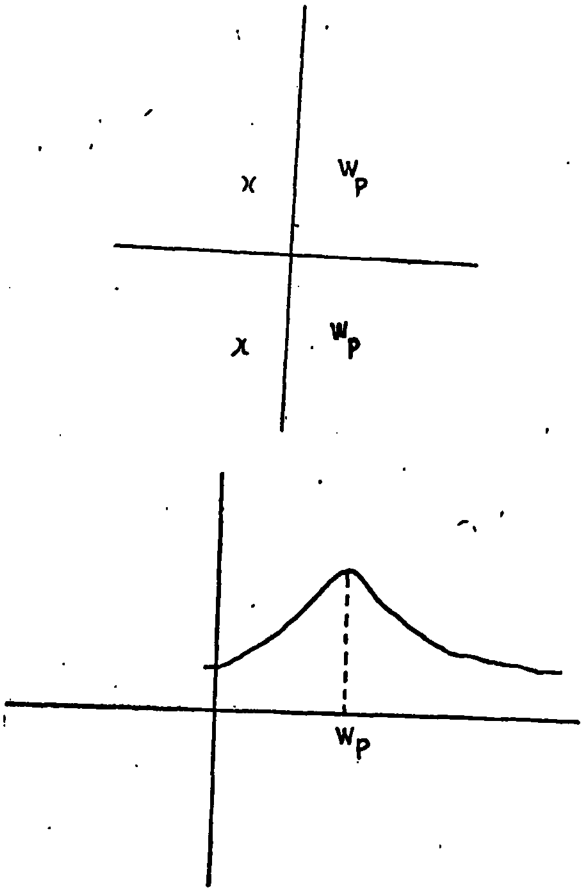


Fig. 2, 3, 2

Case III

5.3.3 $b_1 = 0$ and $a_1 = 0$



The Function will have only a pair of complex poles.

Fig. 5, 3. 3

The selection of the most suitable function depends on the realisability of the function. For reasons shown later T Chelyshev cauer function is selected.

6. Typical Biguad circuit configuration.

6.1 Case (a) $b_1 = 0$.

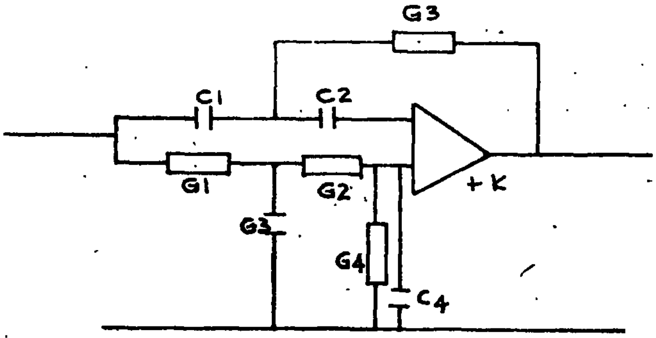


Fig. 6.1

6.2 Case (b) $a_1 = 0$ and $c_1 = 0$

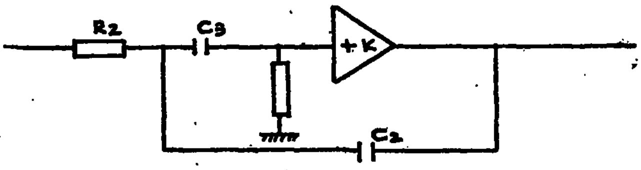


Fig. 6.2

6.3 Case (c) $b_1 = 0$ and $a_1 = 0$

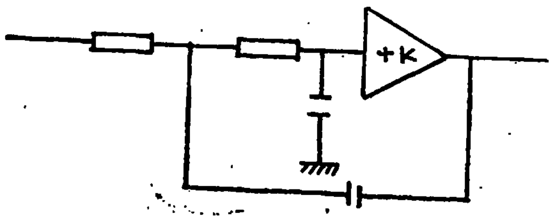


Fig. 6.3

6.4 Factors influencing choice of circuit configuration.

The most important factors influencing choice of circuit configuration are :

(a) Flexibility of independent adjustments of poles and zeros,

(b) Influence of stray effects,

(c) Stability.

6.4.1 Flexibility to Independently Adjust Poles and e Zros

The exact realisation of transfer function representing th reequired response would yield the desired results Achievements of these results therefo.e depends on the tolerance of the components. Components of tolerance as low as 0.1% are available. The cost of the components rises almost exponentially with improvement of tolerance.

Hence in order to reduce the cost of the design it is essential that facilities for tuning of zeros and poles frequencies are incorporated in the circuit. It is also advantageous that the fine adjustments in respect of each zero and pole frequency does not disturb the remaining zeros and poles.

In practice very often it is only possible to minimise the inter-dependency of the variable on the remaining poles and zeros. This is achieved by selecting the component for trimming of the given pole and zero by study of the sensitivity matrix "S" given in Table III. The Trimming components corresponding to the poles and zeros are encircled.

6.4.2 (b) Stability

The fluctuations in ambient temperature gives rise to drifts of component values causing the design parameters to drift from the nominal value. It is essential that such drifts are restricted to be within the specified value to minimise interference and cross-talk. The cumulative drift of a given parameter Y_r is estimated from the sensitivity matrix 'S' and the temperature co-efficient vector $\frac{dx}{x}$ of the components as :

$$\frac{dy}{y} = S \frac{dx}{x}$$

6.4.3 Op. Amps.

The drift caused by Op. Amp. is about 10% of the total drift as mentioned in para 2.2. The drift is minimised by selecting the Op. Amp with the minimum open circuit gain as derived in 4.1.

Components

The passive components R and C has temperature co-efficients of 50×10^{-6} ppm and $50 \pm 250 \times 10^{-6}$ ppm respectively. The drift is estimated assuming that the ambient fluctuations does not exceed 10°C. The temperature compensating network mentioned in Section 2.2 is used to maintain the performance within the Specification.

6.4.4 Stray Effects

The stray effects should be considered when deciding the component tolerance. The stray capacitance of a reasonably well laid out circuit is unlikely to exceed 10 pF. If the permissible cumulative deviation of a parameter from nominal value is 2%, and the tolerance of the components is 1%, then minimum nominal design value of capacitors should not be less than 1000 pF. The corresponding value for resistor is 10 Ohm.

7. Selection of Transfer Function

The Transfer function is selected to satisfy the boundary conditions given in Clause 4 of Appendix 3.

Example to illustrate the design procedure :

Design of a low-pass filter for the Speech filter in the Speech plus Duplex Telegraphs.

The Transfer function is selected to match the boundary conditions given in Clause 4 of Appendix 3, which is reproduced below in Fig. 7.

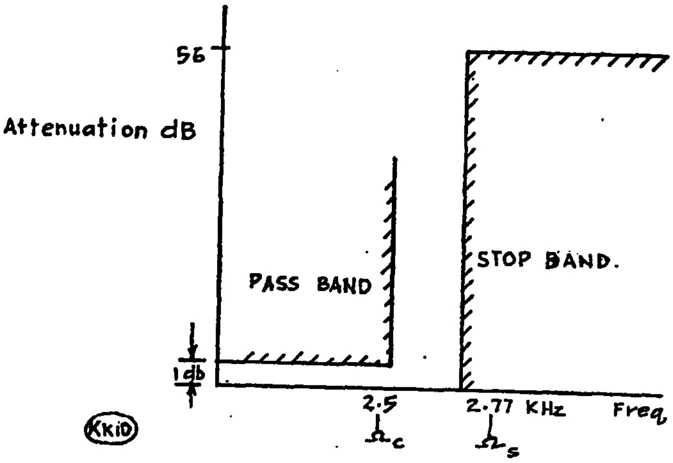


Fig. 7

Max permissible passband tolerance A max is 1 db. However, A max is restricted to 0.28 db to ensure a performance superior to that specified in CCITT.

This will correspond to a reflection factor of 25%.

Stop frequency normalised to passband cut off frequency.

$$s = \frac{2.77}{2.5} = 1.11$$

Hence the corresponding modular angle which is one of the parameters defining the transter function $= \text{Sin}^{-1}\,(1/1.11) = 64.5^0$.

Based on this value the number of stages required is shown to be 9. Vide reference (1).

The required polynomial accordingly defined (Vide ref. 1).

09.25.65

As the transfer function corresponding to the above is not available cascading two similar sections is proposed. The two sections required are both cc 06.25.60 for results better than cc 09.25.65. The transfer function obtained from tables (ref. 1) is given by:

$$\frac{(p^2 + 2.220166)\ (p^2 + 1.432481)}{p^2 + 0.0858p + 1.034194)\ (p^2\ \ 0.388738p + 0.7975019)\ (p^2 + 0.8551492p + 0.333475)}$$

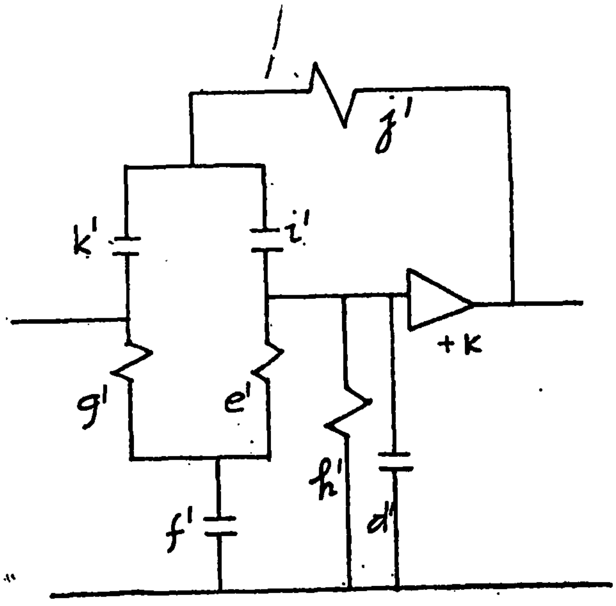


Figure 7.1

The biquads sections are realised using the twin tee sections which are having better senstivity to parameter changes.

Design equations are for a biquad of form

$\dfrac{p^2 + \alpha}{p^2 + \beta p + \gamma}$ shown in Fig. 7.1

$d = 1.0$ F

$e = (2.5)$ S

$f = e^2/\ \ (e - 1)$ F

$g = e/e{-1}$ S

$h = 1.0$ mho

$i = (2.5 - 1)$ far

$j = (i^2\ /i - 1)$ mho

$k = i/j - 1$ far

$$Na = \frac{\alpha f}{\alpha f + eg}$$

$Nb = 1 - Na$

$d^1 = Na$ far

$e^1 = Nae$ mho

$f^1 = Naf$ far

$g^1 = Nag$ mho

$h^1 = Nb$ mho

$i^1 = Nb\ i$ far

$j^1 = Nb\ j$ mho

$k^1 = Nb\ k$ far

$$K = \frac{(2.5\sqrt{\gamma} - \beta)\ (i^1 + k^1)}{i^1\ j^1}$$

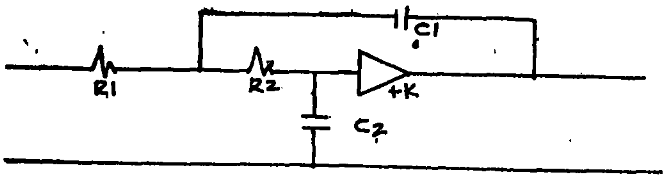


Fig. 7.2

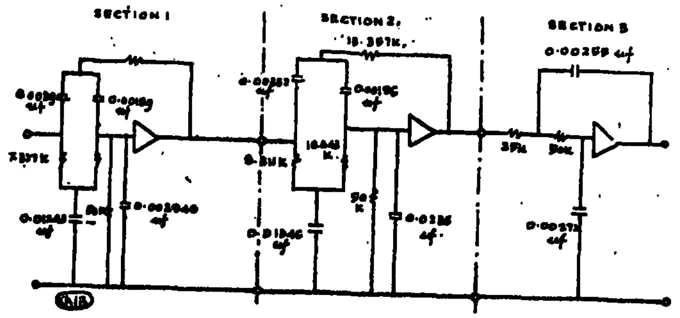


Fig. 7.3

Noise Level

There is no stipulation specifying the basic (idling noise) levels for a S + Dx. The channel mod and demod noise, the specified value of which is in the range 200 – 400 pw may be used as a design guide. The idling noise level may be restricted to valu eabout 10db below the noise level of channel made in pair i.e. about 20-40 pw.

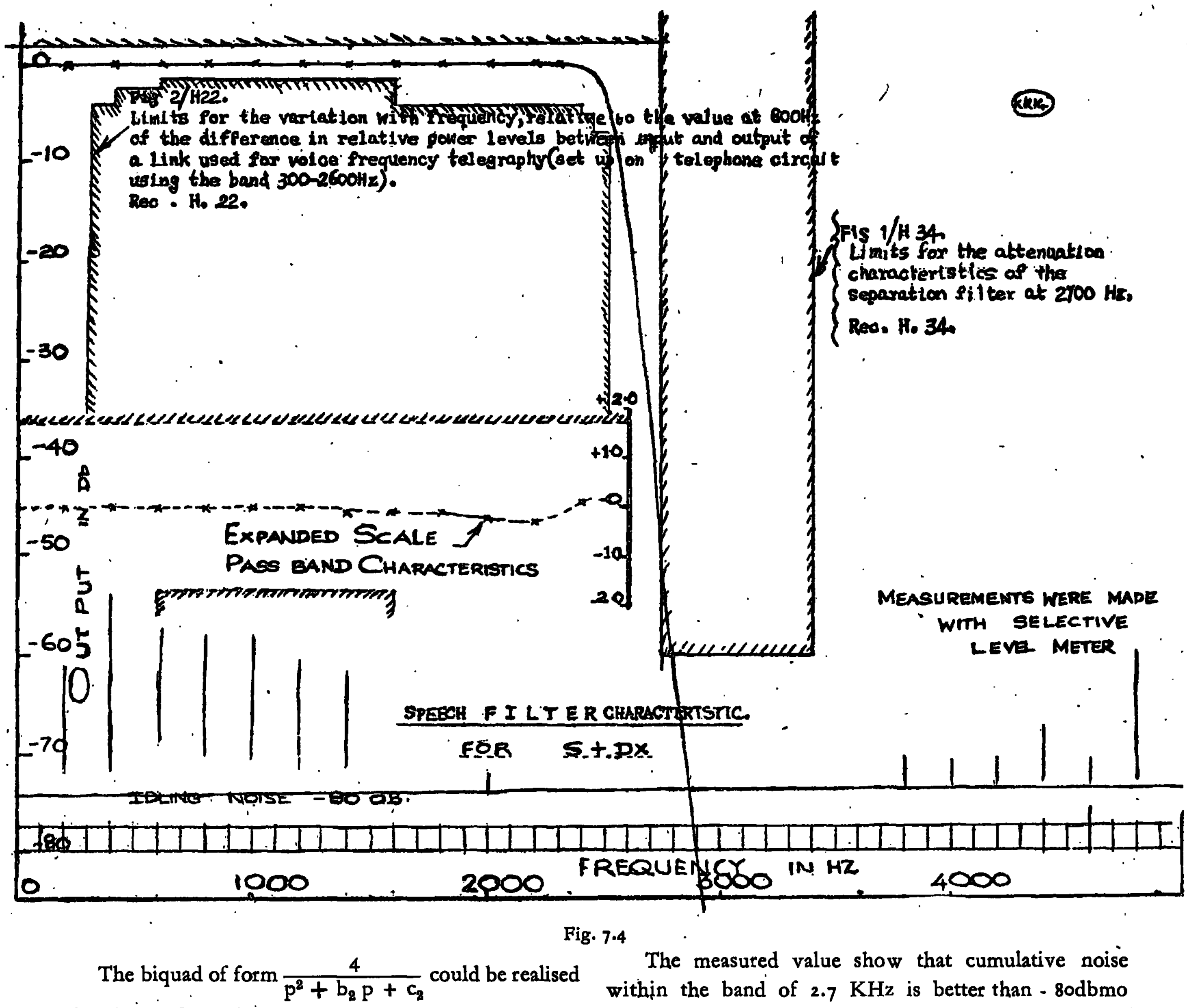


Fig. 7.4

The biquad of form $\dfrac{4}{p^2 + b_2 p + c_2}$ could be realised with the configuration shown in Fig. 7.2.

$$R_1 R_2 C_1 C_2 = \frac{1}{8}$$

$$\frac{1}{R_1 C_1} + \frac{1}{R_2 C_1} + \frac{1}{R_2 C_2} - K \frac{1}{R_2 C_2} = \beta$$

The filter designed as explained above is shown in Fig. 7.3, and the measured response is given in Fig. 7.4.

The measured value show that cumulative noise within the band of 2.7 KHz is better than - 80dbmo i.e. less than 10pw.

8. Financial Consideration

Financial consideration is of utmost importance if production is to be undertaken locally.

The costs were evaluated taking into consideration the R & D and O,H costs. The components of the cost of production of a VFT channel and S+DX estimated on this basis and FOB costs of an imported unit are given below.

	VFT	*S+DX*
	Rs.	Rs.
R & D Costs per channel ...	200	400
Foreign Cost per channel ...	800	1,600
Local Cost per channel ...	700	700
	1,700	2,700
Cost of imported unit (F.O.B.)	16,000	32,000

It is revealed that a locally produced VFT and S+DX units costs almost 10% of the FOB value of an imported unit. The active components used in the circuitry are those manufactured by Motorola and the high stability components are those manufactured by Philips Ltd.

9. Field Trials

One VFT unit fabricated by the R & D Section has been commissioned between Kurunegala and Colombo on 12th September, 1978 and the Sectional Engineer has reported that the system is working very satisfactorily. The S+DX unit designed has been handed over to the Postmaster-General by the Chairman, National Engineering Research & Development Centre on 6th January, 1979 for field trials.

APPENDIX I

Recommendation R.35

STANDARDIZATION OF FREQUENCY-SHIFT-MODULATED VOICE-FREQUENT TELEGRAPH SYSTEMS, FOR A MODULATION RATE OF 50 BAUDS

(*former C.C.I.T. Recommendation B-48, Geneva*, 1956, *amended New Delhi*, 1960, *Geneva*, 1964, *Mar del Plata*, 1968, *and at Geneva*, 1972)

The C.C.I.T.T. *unanimously declares the following view*,

1. The nominal modulation rate should be standardized at 50 bands.

2. For the nominal mean frequencies, the series formed by the odd multiples of 60 Hz should be adopted, the lowest frequency being 420 Hz in accordance with Recommendation R.31, paragraph 1, the mean frequency F_0 being defined as the half-sum of the two characteristic frequencies corresponding to thee permanent start polarity F_A and stop polarity F_Z.

For the new numbering of channels which has been adopted in the international service see Recommendation R.70 *bis*.

3. The mean frequencies at the sending end should not deviate from their nominal value by more than 2 Hz.

4. The unbalance due to the modulation process $\delta = 2\,\frac{(F'_0 - F_1)}{F'_A - F'_Z}$ should not exceed 3%. (This limit provisional and could be revised if necessary).

where F'_A and F'_Z are the two characteristic frequencies measured over a period of 10 seconds;

F_0 is the mean static frequency measured $= \frac{F'_A + F'_Z}{2}$

F_1 is the mean dynamic frequency measured with 1 : 1 rectangular signals during 10 seconds.

Measurement should be made applying to the input of the transmitter 1 : 1 rectangular signals with the build-up and hangover time below 1 μs and with the unbalance below 0.1%.

In the event that in service the transmitter is controlled by an electro-mechanical relay (with a certain transt time), the measurement should also be made with that type of relay inserted between the signal generator 1 : 1 and the input to the transmitter.

Both forms of measurements need not necessarily be included in the maintenance procedure but should be included in laboratory type tests.

Note.—To determine the unbalance due to the modulation process by the method indicated above, it is necessary to measure the frequencies F'_A, F'_Z and F_1 and to calculate the mean frequency F'_0 and the unbalance

$$\delta = 2\,\frac{(F'_0 - F_1)}{F_A - F_Z}$$

A more rapid method for checking whether or not the unbalance is less than the limit fixed is to measure :

the mean dynamic frequency F_1 with 1 : 1 signals during 10 seconds

the mean dynamic frequency F_m with 2 : 2 signals during 10 seconds

$$\delta = 2\,\frac{(F'_0 - F_1)}{F'_A - F'_Z} = 4\,\frac{(F'_0 - F_m)}{F'_A - F'_Z}$$

Substract

$$(F_1 - F_m) = \tfrac{1}{4}\,(F_A' - F'_3)\,\delta \simeq \tfrac{1}{4}\,(F_A - F_3)\,\delta\, 0.4\ \text{Hz}$$

The absolute value of the difference between the two frequencies measured Fe and Fm must be less than 0.4 Hz.

5. The difference between the two characteristie frequencies (corresponding to the start and the stop conditions(should be 60 Hz although a difference of 70Hz may be used by agreement between the Administration concerned. In this latter case, the absolute value of thc unbalance δ due to the modulation process must be less than 3%.

6. The tolerance permitted in this difference should be at most $\pm$ 3 Hz.

7. The total average power transmitted to the telephone line by all the channels of a system is n ma ly limited to 135 microwatts at a point of zero relative level. This sets, for the average power of a telegraph channel (at a point of zero relative level) the limits given in Table 1.

Voice-frequency telegraph system	*Allowable power per telegraph channel at a point of zero relative level* in microwatts	in an absolute power level decibels
12 telegraph channels, or less	11 25	- 19 5
18 telegraph channels	7.5	- 21.25
24 telegraph channels	5.6	- 22.5

8, In operation, the levels of the signals corresponding to continuous stop polarity and continuous start pola:ity should not differ by more than 1.7 dB in the same channel. Both of these levels must be between + 1.7 dB and 1.7 dB with reference to the level given in Table 1.

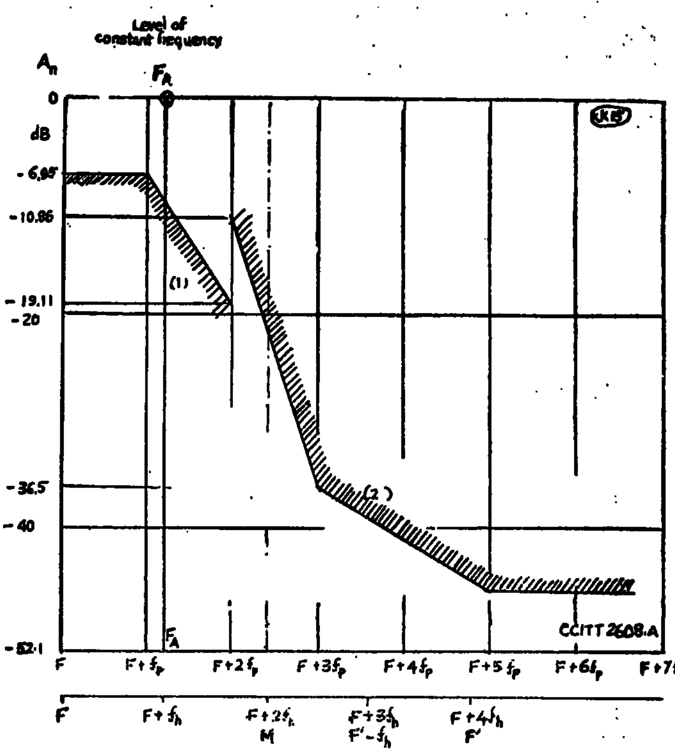
9. The frequency for the transmitted condition corresponding to the start pola ity is the higher of the two chracteristic frequencies and that corresponding to the stop polarity is the lower.

10. In the absence of telegraph current controlling the channel modulator, a frequency should be transmitted within $\pm$5 Hz of the frequency normally transmitted for the start polarity. This frequency need not be sent immediately after interruption of the control current.

11. . he frequency spectrum of the emitted signal, when tr mitting 1 : 1 signals at the modulated rate of $2f_p$ (f_p = frequency of modulation) should be in accordance with the limits specified in Figure - in this diagram t shows the levels of the spectra of different components with respect to the amplitude of the non-modulated carrier as ordinates and the frequencies as abscissae.

12. The receiving equipment should operate satisfactorily when the receiving level falls to .... below the nominal level. The receiving equipment should have been restored to start polarity when receiving level has fallen to 23.5 dB below the nominal level.

The nominal level is the level resulting from the choice of power per channel (Table I) depending on the number of channels (12, 18 or 24) on the circuit.



F carrier frequency of a channel
F frequency of modulation 25 Hz
F frequency snift 30 Hz
F carrier frequency o: the adjacent channel
M centre line between adjacent channels
Curve 1 Lower limit in the pass band
Curve 2 Upper lim t in the stop band

FIGUERE 1/R.35.—**Frequency spectrum for 1 : 1 signals in fregunсy-modulated 50-band-120-Hz spacing voice-frequency telegraph systems**

Choice of the level to control an alarm is left to individual Administrations.

13. On delivery by the manufacturer of 50baud frequency-modulated voice-frequency telegraph equipmente the following values must not be exceeded for the degre of distortion on a telegraph channel.

These values correspond to closed circuit measurements, made with the audio-frequency line terminals of the sending and receiving equipments connected together through an artificial line. Before the se.ie; measurements taken in accordance witl Recommendation R.51 the levels a:e adjusted to their no:mal values, the mean frequencies are checked to see whether they are within $\pm$ 2 Hz of their nominalvalues (point 3 of the Recommendation) and the difference between the two characteristic frequencies is within the permitted tolerance of less than 3Hz (point 6 of the Recommendation). Bias distortion is eliminated by adjustment in the channel receivers. The other channels of the system are modulated with un e ated signals when the effect of inter-channel interference is to be included in the measurement. The;e "unrel signals" can conveniently be 1 : 1 signals from different generators at approximately 50 bauds but synchronous to each other or to the signal on the channel under test.

(a) the transmission levels being normal, the artificial line introducing no frequency drift, but the measured channel being subject to fortuitous distortion due to inte:channel interferen e' 5% for the degree of inherent isochronous distortion,

(b) the level being maintained constant, but at a value different from the normal level, for all constant levels between 8.7 dB above the normal reception level and 17.4 dB below the normal reception level. the other conditions being the original measurement condition: 7% for the degree of inherent isochronous distortion'

(c) in the presence of interference by a single sine-wave frequency equal first to one and then to the other characteristic frequency, with a level of 20 dB below the signal level, the other conditions for the start of measurements being maintained' 12% for the degree of inherent isochronous distrotion (i.e. total distortion including the increase due to the interfering frequency, not distortion due to the interfering frequency alone)'

(d) by introducing a frequency d:ift $\wedge f$Hz of the signals, during transmission through the artificial line, $\wedge f$ being not more than 5, and the initial condition of the test otherwise being produced $5 + 2.5 \ \wedge f$Hz)% for the degree of inherent isochronous distortion the measurements shall be made after the transient effects of changing frequency have ceased.

14. Frequency drifts on modern telephone circuits are generally less than 2 Hz. Hence, it is not necessary to recommend frequency d:ift control.

For circuits on which a maximum frequency d·ift of not greater than ± 2 Hz cannot be guaranteed compensation seems necessary. Two methods can be used,

—compensation for each channel upto about 15 Hz,

—compensation for all the channels by using apilot. In this case, the receiving end must be able to request and obtain a pilot frequency. Administrations should agree among themselves on the advisability of sending the pilot and the choice of frequency, 3300 Hz or, preferably, 300 Hz are recommended, with tolerance of ± 1 Hz The mean power emitted at the relative zero point on this frequency should not exceed that recommended for a telegraph channel in the case of a 24-channel group i.e. —22.5 dB.

15. The number of significant modulation conditions is fixed at two: this number may be increased if necessary, by agreement between the Administ:ations concerned.

Recommendation R.35 *bis*

50-BAUD WIDEBAND VOIC - FREQUENCY TELEGRAFH SYSTEMS

(*Geneva*, 1964)

Voice-frequency telegraph systems for 50-baud channels standardized by the C.C.I.T.T. are described in Recommendations R.31 (for amplitude modulation) and R.35 (for frequency modulation). Systems which comply with these recommendations are those normally recommended by the C.C.I.T.T.

However, it may sometimes be advisable to use a voice-frequency telegraph system for a speed 50 bauds in which the channels have wider spacing than in systems complying with Recommendations R.31 and R.35.

The use of channels with a spacing of more than 120Hz for a modulation rate of 50 bauds offers certain advantages in the following cases ;

1. on connections with not much traffic (which it is not intended to increase to more than 12 channels for a long time to come)'

2. on connections where channels are required to have less distortion than on channels established in accordance with Recommendations R.31 and R.35'

3. as far as maintenance is concerned, wideband equipment requires less attention.

In particular, if telephone circuits carrying voice-frequency telegraph systems are unstable, the ...use... of wideband channels together with f.m. is recommended.

Moreover, if systems are standardized so that only one modulation method is used, the cost of equipmen should be lower.

APPENDIX II

Recommendation H.34 (Geneva, 1972)

SUBDISION OF THE FREQUENCY BAND OF A TELEPHONE-TYPE CIRCUIT BETWEEN TELEGRAPHY AND OTHER SERVICES

1. Allocation of the bands

The specific case considered here is that of frequency subdivision at 2700 Hz of a four-wire circuit into a main band (which can be used for telephony, data, phototelegraphy or facsimile transmission) and a secondary band, above the main band, reserved for FM telegraphy.

2. Main Channel

With the upper part limited in this way, the main channel can be used for :

(a) telephone calls of a reduced quality plus an appropriate signalling system ,

(b) data transmission in accordance with Recommendation V.21, V.23 or V.30 *with* backward channel

(c) phototelegraph transmission in accordance with the normal conditions described in Recommendation T.1 (60 rpm. with amplitude modulation–frequency modulation in any case is not advisable on circuits in land cables: amplitude modulation on submarine cables is still under study):

(d) black-and-white facsimile transmission in accordance with Recommendation T.2 (120 rpm. only, AM or FM).

For services b, c and d above, the filter should be designed to keep the group delay distortion within tolerable limits for these services.

With regard to service a, where applicable, account should be taken of the telephony impairment (about 2dB) due to the limitation of the frequency band (see Recommendation G.113). It will be recalled that, in accordance with point 6.8 of Recommendation D.1, Administrations are not obliged to guarantee the quality of transmission of calls sent to or received from users on the public network over a leased circuit.

3. Telegraph Channels

The following are the preferred arrangements of telegraph channels in the secondary band in the case of a normal 300-3400 Hz telephone-type circuit :

(1) four 120 Hz spaced channels (Nos. 121, 122, 123 and 124):

(2) two 120 Hz channels and one 240 Hz channel (Nos. 123, 124 and 211);

(3) two 240 Hz channels (Nos. 211 and 212);

(4) one 480 Hz channel (No. 406).

The numbering, modulation and other characteristics of the telegraph channels should comply with Recommendations R.35, R.37, R.38, A and R.70 *bis*, as far as possible considering the reduced transmission level, which may result in sub-standard performance.

Where the upper limit is reduced to 3050 Hz (as in telephone channels complying with Recommendation G.235) it will only be possible to use two 120-Hz channels (Nos. 121 and 122) or one 240-Hz channel (No. 211-with the recommended frequency subdivision.

With the same subdivision, the main channel may be used for :

—telephone calls,

—facsimile (including phototelegraphy),

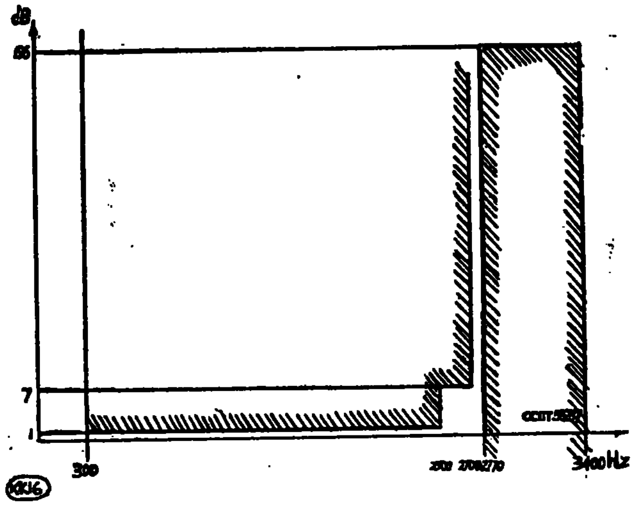
and the secondary channel for :

—data transmission by telegraph channel upto 200 bauds (100 bauds on submarine cables).

However, any private system may be used, depending on the characteristics of the portion of the band available.

4. Filters

For the protection of the telegraph channels from interference by speech components in the upper frequency range a filter must be used at the sending end. The recommended filter attenuation characteristic is defined by the limits shown in Figure 1,H.34.



Note.— This filter protects the telegraph channels from the signals transmitted on the main channel. The filters mentioned in Recommendation R.35 for protection in the opposite direction can be relied on' when the secondary channel is used for other purposes, special precautions should be taken to protect the main channel.

When non-speech transmission is required in the main band the peak-to-peak delay distortion of this filter should not exceed 0.15 ms over the range 1100 to 2300 Hz. The maximum absolute delay in the range 300-2300 Hz should not exceed 2 ms.

Sufficient protection of the main band from interference by the telegraph signals in the secondary band is assured by a similar filter at the receiving end. It is assumed that the telegraph channels are provided with filters so as to meet the provisions of Recommendations R.35, R.37 or R.38, A.

5. Levels

The general principle concerning levels for each type of service is that the allowable mean signal power is proportional to the bandwidth assigned.

Of the maximum permissible 1-minute mean loading of 50 uW (—13 dBmo), 10 uW are allocated to the secondary band and the remaining 40 uW to the main band. In the case of telephony this implies that normal levels for speech and signalling can be retained (given in Recommendation G.223 as 32 uW).

6. Limitation of Amplitude

It may be desirable to impose a limit in the main band path so that the onset of non-linearity in the common transmission path will not cause intermodulation and possible interference with the telegraph channels.