Technical performance of long chains of u.h.f. television broadcast transmitters

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Abstract

The u.h.f. colour-television transmission networks of the IBA and BBC have expanded considerably in the last few years, to the point where 97% of the population is now covered. In some areas, because of topographical difficulties, the signal may have to pass through several main or relay stations before it is received by the viewer. This paper considers the particular problems of transmission equipment and the technical performance of main and relay stations; it also gives examples of the predicted performance of typical transmission chains using a computer program developed by the IBA. The paper concludes by suggesting that the terminal station performance may in future be predicted more accurately using statistical data.

1 Introduction

In 1971, the 'white book' – 'Specification of television standards for 625-line System I transmissions' – was published jointly by the BBC and ITA. Appendix 4 of the publication gives the estimated performance of a network from the coder input to the output of a rebroadcast main station. Since then, the broadcast transmission networks in the UK have grown, and it has become necessary to be able to predict the performance of a transmission chain with a number of main and relay stations in series.

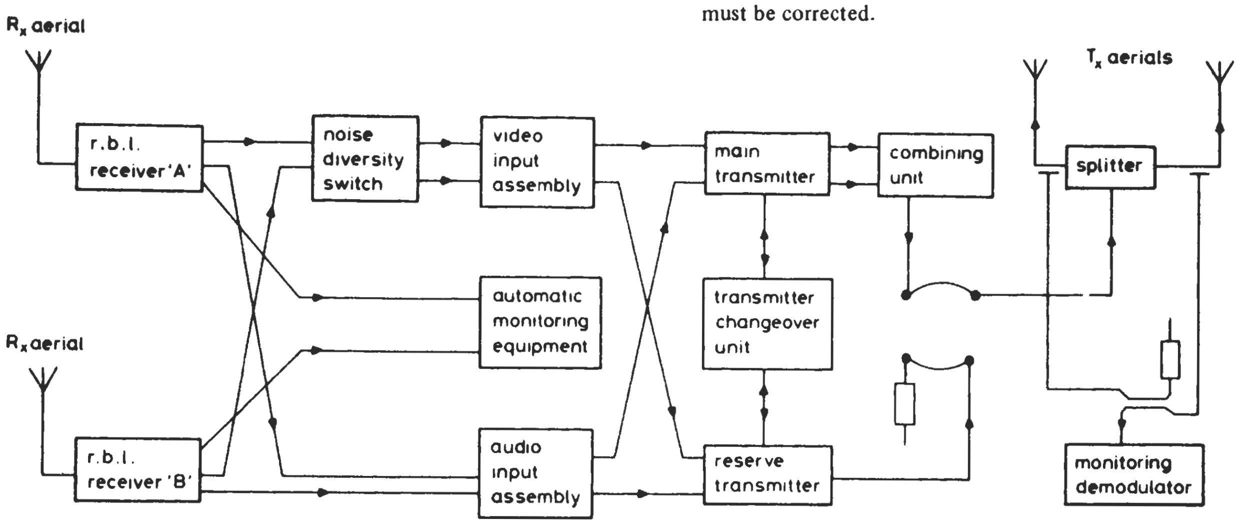

Fig. 1
Block diagram of rebroadcast main station

r.b.l. = rebroadcast link

2 Transmitter network

Post Office circuits, which may be either coaxial lines or microwave links, connect the studio to each key main station of a network. Generally, very little distortion is introduced by these circuits. The key main stations are positioned to cover large areas of population.

To include the other large pockets of unserved population, more high-power transmitters have been constructed at sites that can receive the signal from the key main station. The signal is demodulated by a high grade demodulator, often synchronous, to provide the video and audio signals for remodulation. A block diagram of such a transmitter is shown in Fig. 1.

Where pockets of population are still unserved, because they are shielded from the main station u.h.f. transmissions, relay stations are required. These relay stations also operate in the u.h.f. band; they handle both the video and audio signals simultaneously, and do not involve demodulation and the subsequent remodulation processes. A block diagram of a typical transposer is shown in Fig. 2.

A typical transmission chain is shown in Fig. 3 and may consist of up to five rebroadcast main or relay stations in series.

3 Factors affecting technical performance of each equipment

To achieve high efficiencies from the amplifying devices used in modern u.h.f. transmitters, the full transfer characteristic of the device has to be used. The typical transfer characteristic of a klystron is shown in Fig. 4. The nonlinear amplitude and phase characteristics must be corrected.

When a common amplifier is used to amplify the vision and sound signals simultaneously, as in transposers or in some reserve transmitter equipment installed at main stations, the amplitude and phase nonlinearity of the amplifying device gives rise to intermodulation between the vision, sound and chrominance carriers. So far as the received signal is concerned, the main products of interest are the intermodulation product at 1·57 MHz, and the crossmodulation of the vision carrier on to the sound carrier. The former gives rise to a banding effect on highly saturated colour areas of a picture (similar to moiré in a video tape recorder), and the latter can give rise to sound buzz.

An additional constraint with broadcast equipment is that the bandshape and bandwidth of the transmission must be accurately defined. Radiation outside the allocated channel must be very low to avoid interference in an adjoining reception area, where adjacent channel transmissions may be employed. Thus the filtering requirement for broadcast equipment is very stringent, and this gives rise to group-delay distortion that must be held within close limits to ensure that the cumulative distortion in the transmission network does not become excessive.

Because, at both rebroadcast main stations and relay stations, the input signal is received offair from the parent station, the propagation

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path must be included as an element in the chain. This can introduce frequency-response errors, multiple echoes, and cochannel interference to the required signal. The received signal strength and the noise figure of the receiver determine the signal/noise ratio.

4 Determining the performance of long transmission chains

To determine the performance of a long transmission chain, the performance of each element of the chain must be known. The performance specification of the elements in an IBA chain are shown in Table 1. A computer program has been devised which uses this information to predict the terminal performance of a chain of equipment, and the following information is inserted from the reception tests made at each site:

(*a*) terminated signal level in millivolts
(*b*) maximum deviation of sound/vision power ratio in dB
(*c*) subjective grading of delayed images
(*d*) subjective grading of cochannel interference
(*e*) noise figure of receiver.

Table 2 shows the performance of two chains of transmitters, one including a rebroadcast main station using a synchronous receiver. In each case, the following figures have been assumed for each propagation path:

(i) terminated signal level – 2 mV
(ii) receiver noise figure – 8 dB
(iii) maximum deviation of sound/vision power – 1 dB
(iv) subjective grading of delayed image – 1*
(v) subjective grading of cochannel interference – 1*.

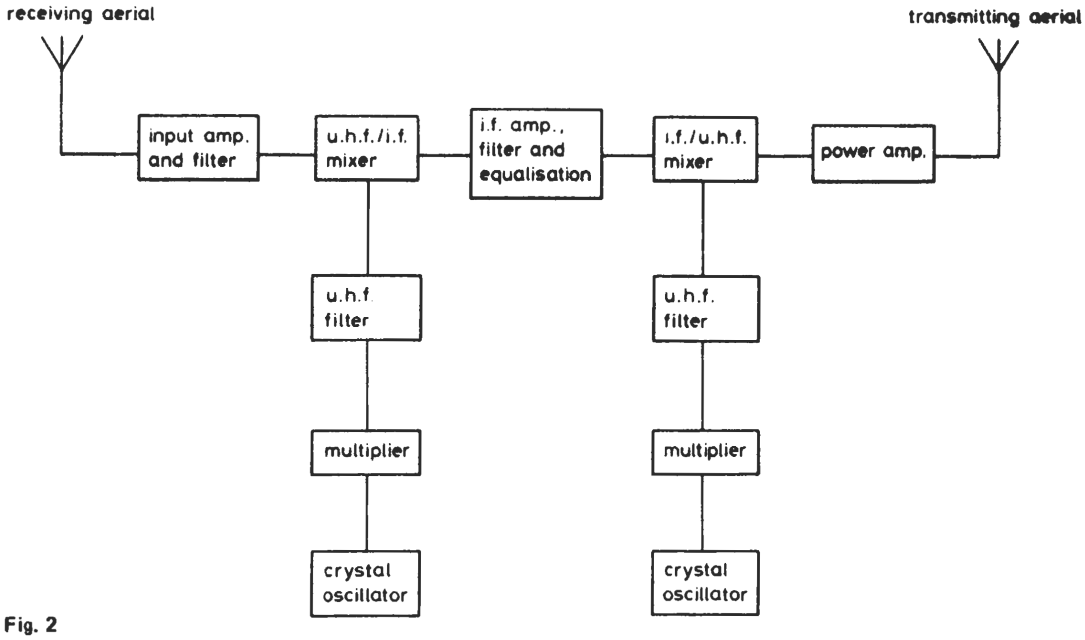

Fig. 2
Block diagram of typical transposer

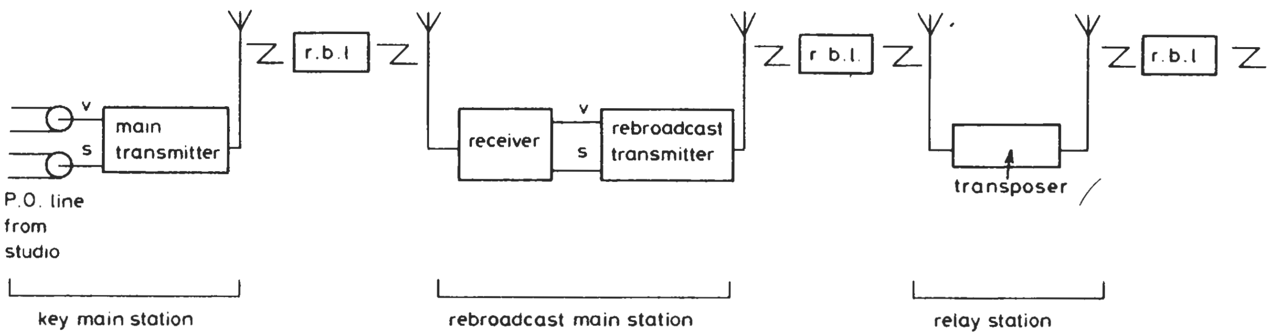

Fig. 3
Typical transmission chain

r.b.l. = rebroadcast link

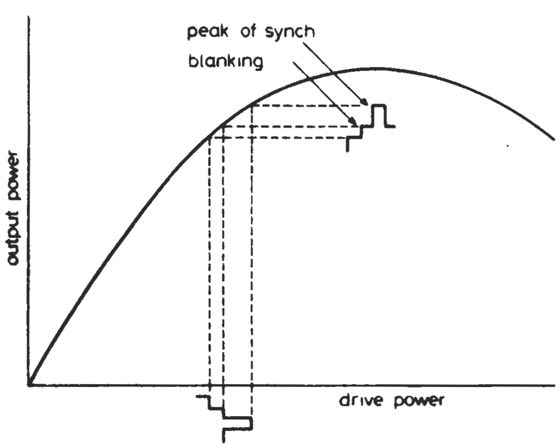

Fig. 4
Klystron transfer characteristic

The signals are progressively degraded as the broadcast chain is extended, and clearly some limit has to be applied that must not be exceeded if a satisfactory service is to be provided at the end of the chain. In conjunction with the BBC, subjective tests were carried out to determine the limit for each parameter. Two Standards P and Q were established, depending on the importance of the terminal station. Standard P applies where the total coverage, including any dependent relay station, exceeds 2000 people. Standard Q applies to the last station in the chain if the population coverage is less than 2000 people.

The limits of each parameter to be met for standards P and Q are shown in Table 3.

5 Future work

The computer program assumes the laws of addition for each parameter, as defined in Table 2. These generally conform to CCIR Recommendation 451-1[2], except where practical experience has

* Quality grading using the six-point scale where 1 equals excellent

Table 1
PERFORMANCE SPECIFICATION FOR EACH ELEMENT OF A TRANSMISSION NETWORK

Parameter[1]	Typical PO line limits*	Transmitter limits	Transposer limits	Synchronous receiver limits	Envelope receiver limits
Vision performance					
Departure from ideal Sound/vision power ratio, dB	–	+0·89 to −0·99	+0·47 to −0·5	+0 to −0	+0 to −0
Peak white level, %	6·0	2·0	2·0	1·0	1·0
Black level, %	2·0	2·0	2·0	1·0	1·0
Carrier frequency, parts in 10^7/month		5·0	5·0	–	–
Luminance/chrominance gain, %	5·0	4·0	5·0	2·0	4·0
Luminance/chrominance delay, ns	20·0	15·0	20·0	10·0	10·0
Echoes with delays $>1\,\mu s$ §		–	–†	–†	–†
2T pulse response, % K	1·0	2·0	2·0	1·0	1·5
Bar/2T pulse ratio, %	4·0	4·0	4·0	1·0	2·0
10 µs bar response, % K	1·0	1·0	1·0	1·0	1·0
50 Hz square wave, % K	1·5	0·5	0·5	1·0	1·0
Chrominance/luminance crosstalk, %	3·0	1·0	1·0	2·0	2·0
Luminance nonlinearity, %	2·0	4·0	7·0	1·0	4·0
Differential gain, %	2·0	3·0	6·0	1·0	5·0
Differential phase, degrees	1·0	3·0	3·0	1·0	3·0
Intermodulation products, dB	–	–	−52·0	−60·0	−55·0
Cross-modulation vision to sound, %	–	–	7·0	–	–
Incidental phase modulation, degrees	–	5·0	5·0	–	–
Cochannel interference §	–	–	–†	–†	–†
Unweighted noise, dB	−60·0	−54·0	–†	–†	–†
Luminance weighted noise, dB	−60·0	−60·0	–†	–†	–†
Chrominance weighted noise, dB	−58·0	−54·0	–†	–†	–†
L.F. noise, dB	−35·0	−50·0	−50·0	−56·0	−56·0
H.F /L.F. converted noise, dB	–	–‡	–	–	–
Sound performance					
Sound level stability, dB	+0·9 to −1·0	+0·47 to −0·5	+0 to −0	+0·47 to −0·5	+0·47 to −0·5
Sound distortion at +8 dBm, %	3·0	1·0	–	1·0	1·0
Unweighted noise, dB	−35·0	−60·0	−56·0	−50·0	−50·0
Weighted noise, dB	−39·0	−70·0	−66·0	−60·0	−60·0
Amplitude/frequency response, dB	+0·9 to −1·0	+0·89 to −0·99	+0 to −0	+0·47 to −0·5	+0·47 to −0·5
Pilot tone level, dB	–	+1·28 to −1·5	+0·47 to −0·5	+0·89 to −0·99	+0·89 to −0·99

* These limits are typical values and depend on circuit length. Figures given are for Crystal Palace, and are guaranteed limits.
† These figures are determined by the r.b.l. data.
‡ Determined by incoming noise.
§ Subjective grading of quality using the six-point scale where 1 equals excellent.

shown that a closer approximation may be achieved by an alternative law. In some cases, these laws are by no means definitive, and the limitations of applying such simple mathematical assumptions are well known. For example, from Table 2, the 2T pulse response %K rating exceeds the limit for standard P at the fourth station in the chain, which in practice is rarely a problem.

For parameters where the deterioration through a transmission network is random, a statistical approach is clearly more appropriate.

With over 200 relay stations now in service, a large amount of statistical data is now becoming available that will enable us to apply a more meaningful figure for the equipment performance and include such factors as fading margin. It is hoped, within the next year, to improve the computer program to include these statistical data. This will enable a more accurate prediction to be made for the performance of each element in the chain, including the probability and percentage of the time that this performance can be maintained.

6 Acknowledgments

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7 References

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2 Recommendation 451-1: 'Requirements for the transmission of television signals over long distances (system I only)'. CCIR 12th Plenary Assembly, New Delhi, 1970. Vol. 5, pp. 193–213
3 CCIR Report 405-1: 'Subjective assessment of the quality of television pictures'. CCIR 13th Plenary Assembly, Geneva, 1974, Vol. 11, pp. 75–83

8 Appendix

Addition of subjective quality gradings

Under practical viewing conditions, a number of impairments may arise simultaneously. A law of addition of impairments can be of great benefit. An empirical law that has been used states that if $U_1, U_2, \ldots, U_r, \ldots, U_n$ are the respective normalised mean scores for n unrelated impairments taken separately, the normalised mean score U for all impairments taken simultaneously is given by:[3]

$$\frac{1}{U} \quad 1 = \sum_{r=1}^{n} \left(\frac{1}{U_r} - 1\right) \tag{1}$$

If we let

$$I = \left(\frac{1}{U} - 1\right),$$

where I is a unit of subjective impairment (imps), they may conveniently be directly summed.

In practice, using a six-point quality scale, where 1 is excellent, the following relationship approximately holds (Fig. 5):

$$U = \left(\frac{6-G}{5}\right)$$

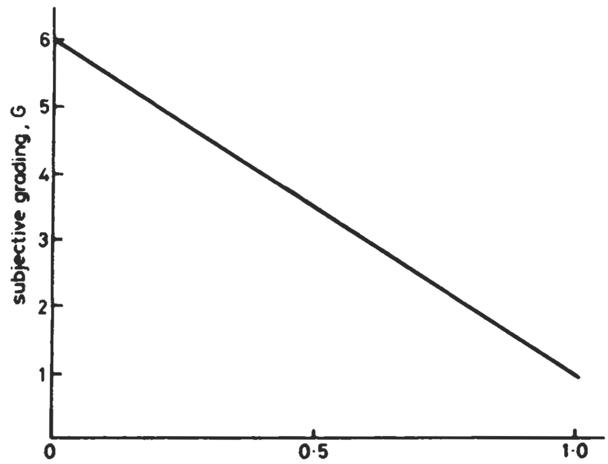

Fig. 5
Approximate relationship between a six-point grading scale and mean score

Table 2
CALCULATED PERFORMANCE OF A TRANSMISSION NETWORK

Parameter	Main station	Transposer 1	Transposer 2	Transposer 3	Main station	Rebroadcast receiver output	Rebroadcast main station	Transposer 1	Transposer 2	Transposer 3	Laws of addition†
Vision performance											
Sound/vision power ratio, dB	+0·9 to −1·0	+1·2 to −1·4	+1·4 to −1·6	+1·6 to −1·9	+0·9 to −1·0	+0 to −0	+0·9 to −1·0	+1·2 to −1·4	+1·4 to −1·6	+1·6 to −1·9	2·0
Peak white level, %	2·9	3·6	4·1	4·5	2·9	3·1	3·7	4·2	4·7	5·1	2·0
Black level, %	2·0	2·8	3·5	4·0	2·0	2·2	2·0	2·8	3·5	4·0	2·0
Carrier frequency stability, parts in 10^7/month	5·0	7·1	8·7	10·0	5·0	0·0	5·0	7·1	8·7	10·0	2·0
Luminance/chrominance gain, %	4·8	10·4	13·9	16·7	4·8	9·3	10·1	13·7	16·5	18·9	2·0
Luminance/chrominance delay, ns	21·7	38·2	51·6	63·5	21·7	31·7	38·2	51·7	63·5	74·4	1·5
Echoes with delays > 1 μs*	0	1·0	1·0	1·0	0·0	1·0	1·0	1·0	1·0	1·0	0·0
2T pulse response, % K	2·1	2·9	3·6	4·2	2·1	2·4	3·1	3·8	4·3	4·8	2·0
Bar/2T pulse ratio	5·1	8·7	11·6	14·3	5·1	7·0	8·9	11·8	14·4	16·8	1·5
10 μs bar response, % K	1·5	2·0	2·5	2·9	1·5	2·0	2·5	2·9	3·2	3·6	1·5
50 Hz square wave, % K	0·5	0·8	1·0	1·3	0·5	1·2	0·5	0·8	1·0	1·3	1·5
Chrominance/luminance crosstalk, %	1·5	1·8	2·1	2·3	1·5	2·5	2·7	2·9	3·0	3·2	2·0
Luminance nonlinearity, %	5·1	9·6	13·3	16·5	5·1	5·4	7·5	11·5	14·9	17·9	1·5
Differential gain, %	3·5	7·7	10·9	13·7	3·5	3·8	5·4	9·1	12·1	14·8	1·5
Differential phase, degrees	3·2	4·9	6·3	7·7	3·2	3·5	5·2	6·6	7·9	9·1	1·5
Intermodulation products, dB	–	−52	−49	−47	–	−60	−60	−51	−49	−47	1·0‡
Cross-modulation vision to sound, %	0	7·0	9·9	12·1	0·0	0·0	0·0	7·0	9·9	12·1	2·0
Incidental phase modulation, degrees	5·0	7·9	10·4	12·6	5·0	0·0	5·0	7·9	10·4	12·6	1·5
Cochannel interference*	0·0	1·0	1·0	1·0	0·0	1·0	1·0	1·0	1·0	1·0	0·0
Unweighted noise, dB	−53	−48	−46	−44	−53	−48	−47	−45	−44	−43	1·0
Luminance weighted noise, dB	−58	−54	−51	−50	−58	−54	−53	−51	−50	−49	1·0‡
Chrominance weighted noise, dB	−53	−51	−50	−49	−53	−51	−49	−48	−48	−47	1·0‡
L.F. noise, dB	−50	−47	−45	−44	−50	−50	−50	−47	−45	−44	1·0‡
H.F./L.F. converted noise, dB	−79	−79	−79	−79	−79	−79	−64	−64	−64	−64	1·0‡
Sound performance											
Sound level stability, dB	+1·0 to −1·1	+1·0 to −1·1	+1·0 to −1·1	+1·0 to −1·1	+1·0 to −1·1	+1·1 to −1·2	+1·2 to −1·4	+1·2 to −1·4	+1·2 to −1·4	+1·2 to −1·4	2·0
Sound distortion at −8 dBm, %	3·2	3·2	3·2	3·2	3·2	3·3	3·5	3·5	3·5	3·5	2·0
Unweighted noise, dB	−48	−47	−47	−46	−48	−47	−47	−47	−46	−46	1·0‡
Weighted noise, dB	−52	−52	−52	−51	−52	−51	−51	−51	−51	−51	1·0‡
Amplitude/frequency response, dB	+1·4 to −1·6	+1·4 to −1·6	+1·4 to −1·6	+1·4 to −1·6	+1·4 to −1·6	+1·5 to −1·9	+1·9 to −2·4	+1·9 to −2·4	+1·9 to −2·4	+1·9 to −2·4	1·5
Pilot tone level, dB	+1·3 to −1·5	+1·3 to −1·5	+1·3 to −1·5	+1·3 to −1·5	+1·3 to −1·5	+1·5 to −1·9	+1·9 to −2·5	+1·9 to −2·5	+1·9 to −2·5	+1·9 to −2·5	2·0

* Subjective grading of quality using the six-point scale where 1 equals excellent

† Laws of addition – 1·0 corresponds to arithmetic sum
1·5 corresponds to three-halves power law
2·0 corresponds to root sum squared

e.g. for a typical three-tandem system having distortion of A_1, A_2, A_3, respectively
By arithmetic sum, total distortion $= A_1 + A_2 + A_3$
By three-halves power law, total distortion $= (A_1^{3/2} + A_2^{3/2} + A_3^{3/2})^{3/2}$
By root sum squared, total distortion $= (A_1^2 + A_2^2 + A_3^2)^{1/2}$
For addition of subjective gradings, the following formula has been used (Appendix 8):

$$G_{Tot} = 6 - \frac{5(6 - G_1)(6 - G_2)}{24 + G_1 + G_2 - G_1 G_2}$$

‡ To apply this law the noise expressed as dB must be converted to noise power

Table 3
PERFORMANCE LIMITS FOR STANDARDS P AND Q

Parameter	Standard P	Standard Q
Sound/vision power ratio, dB	−5 dB to −11 dB	−5 dB to −13 dB
Luminance/chrominance gain, %	+26 to −37	+26 to −50
2T pulse response % K for delayed images > 1 μs	3%	4%
2T pulse response % K for delayed images up to 1 μs	4%	6%
Intermodulation products, dB	−48	−40
Unweighted noise, dB	−39	−33

For a simple system involving the addition of two six-point quality scales, the following relationship is true:

$$I_{Tot} = I_1 + I_2$$

or

$$\left(\frac{1}{U_{Tot}} - 1\right) = \left(\frac{1}{U_1} - 1\right) + \left(\frac{1}{U_2} - 1\right)$$

Therefore,

$$\left(\frac{5}{6 - G_{Tot}} - 1\right) = \left(\frac{5}{6 - G_1} - 1\right) + \left(\frac{5}{6 - G_2} - 1\right)$$

and

$$\frac{5}{6 - G_{Tot}} = 1 + \left(\frac{G_1 - 1}{6 - G_1}\right) + \left(\frac{G_2 - 1}{6 - G_2}\right)$$

$$= \frac{24 + G_1 + G_2 - G_1 G_2}{(6 - G_1)(6 - G_2)}$$

Therefore

$$G_{Tot} = 6 - \frac{5(6 - G_1)(6 - G_2)}{24 + G_1 + G_2 - G_1 G_2}$$

It should be noted that although, strictly speaking, these additional laws apply to unrelated impairments, cochannel interference may be considered as an unrelated impairment because the interfering frequency is unlikely to be exactly the same on both signals. Similarly, this holds for echoes greater than 1 μs for which it is unlikely that the echoes will have the same time delay.