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DECIBELS AND RELATED UNITS ENCOUNTERED IN TRANSMISSION SYSTEMS

dB
dBr
dBm, dBw, dBk
dBmO
vu
dBmp, pwp
dBrn, dBrnc
dBa
dBv
dBx
dBmOp
dBrnO, dBaO, vuO
dB, phon
Neper, N, Nm, NmO, Nr, dN, etc
Zero relative level point, TLP
Test level, Line-up level

THE OVERSEAS TELECOMMUNICATIONS COMMISSION
(AUSTRALIA)

Decibels and Related Units Encountered In Transmission Systems

INTRODUCTION

The origin of the use of logarithmic units in communications is related to the fact that human audio and visual senses react in a manner which varies as the logarithm of the stimulus. These units convey a far clearer picture of proportional changes than absolute expressions allow, and furthermore, permit proportional changes to be manipulated by simple addition and subtraction.

Signal levels are sometimes used which have an absolute value of, say, one hundred thousand million million times the absolute value of the lowest noise levels which are encountered. When this enormous range is expressed logarithmically, viz., as 170 dB, it is far easier to manipulate. There is a danger, however, that the use of the logarithmic expressions tends to lessen our ability to visualise the real magnitude of these quantities in terms of absolute units.

Engineers concerned with transmission systems have developed the use of logarithmic units into a complex and sometimes confusing array of derived units (dBmO, dBrnc, dBr, etc.). This Bulletin attempts to clarify the meaning of most logarithmic units found in communications literature.

1. Basic Units

(i) **dB**

Relative power levels are normally expressed in decibels (dB). Taking two power levels, P_1 and P_2, the level of P_1 relative P_2 is defined as —

$$x \text{ dB} = 10 \log_{10} \frac{P_1}{P_2}$$

Notes: (a) If x is positive, then the power level of P_1 is normally stated as being "x dB above P_2" while conversely if x is negative then the power level of P_1 is stated as being "x dB below P_2".

Ratios between voltages (V) across, or currents (I) in, identical impedances are expressed in decibels by —

$$x \text{ dB} = 20 \log \frac{V_1}{V_2}$$

$$x \text{ dB} = 20 \log \frac{I_1}{I_2}$$

(b) Decibel units have been used to express other ratios which are not derived from the decibel's fundamental definition as a power ratio. It is common, but incorrect, practice to speak of current and voltage gains in decibels even when the impedances associated with the voltages or currents are not identical.

(ii) **dBr**

A point in a transmission system may be designated **x dBr** if a test tone experiences a power gain of x dB from the reference point known as the zero relative level point to the point in question.

Notes: (a) The zero relative level point is defined below in Section 6.

(b) By using dBr units, the level relativity of various points in a system may be expressed without reference to test tone level, in much the same way as relative hydrostatic heads in a hydraulic system may be manipulated without reference to height above sea level.

(c) Test tones vary with Administrations. Frequencies of 800 Hz or 1000 Hz may be used at a level of 0.1 milliwatt or 1.0 milliwatt at the zero relative level point.

(iii) **dBm**

The absolute power level of a signal **P** milliwatts, measured in decibels relative to a power level of 1 milliwatt, is denoted in **dBm.**

$$x \text{ dBm} = 10 \log_{10} P$$

Note: Some references employ the terms dBw and dBk which respectively denote decibels relative to 1 watt and decibels relative to 1 kilowatt.

(iv) **dBmO**

The term **x dBmO** at a point in a transmission path is used to mean a power level of x dB relative to the level which would appear at that point if 1 milliwatt were applied at a preceding point of zero relative level in the same path, i.e., the signal would read x dBm at a point of zero relative level.

Note: It follows that a reading of x dBm at an r dBr point is expressed as (x—r) dBmO.

(v) **vu**

The term **x vu** is used to mean an absolute volume level of a complex electrical wave which is x dB above a reference volume of 0 vu. 0 vu corresponds to the reading on the meter when a 1 milliwatt 1,000 Hz tone in a 600 ohm circuit is applied. The measurement is made using a special volume unit indicator in a specified manner.

Notes: (a) The volume unit indicator is normally bridged across a 600 ohm line. Its total impedance is 7,500 ohms of which 3,600 ohms is usually in the form of an external series resistor and 3,900 ohms consists of a suitably calibrated variable attenuator.

(b) Reference volumes for other types of volume measurements which use calibrating tones of 1.66 milliwatt (0 dBv in 600 ohms — see (ix)) and 6 milliwatts may be found in the literature.

2. Units Involving Weighting

When an absolute power level is measured on a meter which incorporates an amplitude/frequency weighting curve, the measurement is known as "weighted". Various types of weighting networks are in use and it is necessary that the particular type of weighting be specified.

(vi) **dBmp**

A signal of "**x dBmp,** using 1960 C.C.I.T.T. telephone weighting" has an absolute power level of x dbm after passing through that particular weighting network. This signal gives the same reading as a calibrating tone of x dBm, the frequency of which will depend on the particular weighting specified.

Notes: (a) The 1960 C.C.I.T.T. telephone weighting network will reduce flat random noise in a 4 KHz spaced channel by 2.5 dB, and in a 3 KHz spaced channel by 2.3 dB.

(b) The "p" is added to the unit abbreviation to indicate that measurements are made with a psophometer. Likewise, signal strength measurements using other units may have a "p" added to indicate the use of psophometric weighting. Thus **pwp** indicates picowatts psophometrically weighted.

(vii) **dBrn**

The term **x dBrn** is used to mean a weighted noise level in a telephone channel which gives the same reading as a 1,000 Hz tone of (–90 + x) dBm when measured with either an early type of Western Electric noise measuring set (which was once in general use within the Bell Telephone System) or with the Western Electric Type 3A noise measuring set.

Notes: (a) dBrn = dB above reference noise.

(b) Sometimes, weighted measurements made with the Type 3A set are expressed dBrnc, in order to indicate that the C-message weighting curve is employed as opposed to 144-line weighting used with the early set.

(viii) **dBa**

The term x dBa is used to mean a weighted noise power level in a telephone channel which gives the same reading as a 1,000 Hz tone of (–85 + x) dBm when measured with the Western Electric Type 2B noise measuring set.

Notes: (a) dBa = dBrn adjusted.

(b) Adjustment was considered necessary to ensure that flat random noise measurements gave the same numerical reading when applied to both the early type measuring set (which used 144-line weighting) and the Type 2B noise measuring set (which used F1A-line weighting).

3. Miscellaneous Units

(ix) **dBv**

The term **x dBv** is used to mean an absolute voltage of a signal V volts which is x dB relative to 1 volt, such that

$$x \text{ dBv} = 20 \log_{10} V$$

(x) **dBx**

The term **x dBx** is used within the Bell Telephone System to indicate crosstalk coupling relative to a reference coupling, when such measurements are made with standard weighted noise measuring sets. Reference coupling exists when the crosstalk attenuation between the disturbing and disturbed circuit is 90 dB.

Thus if the crosstalk attenuation between two circuits is CdB, the cross talk may be expressed as (90 — C) dBx.

Note: This unit was introduced to take account of the different interfering effects of different frequencies and is intended to apply to measurements using standard noise measuring sets.

(xi) **dBmOp**

The term **x dBmOp** is used to mean an absolute power level as measured with a specified weighting network and which gives the same reading as a calibrating tone with a level of x dBmO. The frequency of the calibrating tone will depend on the particular weighting specified.

(xii) **dBrnO**
(xiii) **dBaO**
(xiv) **vuO**

Measurements in dBrn, etc., may be converted to dBrnO, etc., by adjusting the reading by the same algebraic quantity as would be used to adjust dBm measurements made at the same point to dBmO.

4. Sound Levels

(xv) **The Decibel**

The level of a sound of intensity L watt cm^{-2} is expressed in decibels as —

$$xdB = 10 \log_{10} \frac{L}{L_0}$$

where L_0 is a reference level equal to 10^{-16} watt cm^{-2}.

Note: Since sound intensity, L watt cm^{-2}, is related to sound pressure, P dyne cm^{-2}, by the relationship

$$L = \frac{P^2}{dc} \times 10^{-7}$$

where d is the density of the medium (.001205 gram cm^{-3} for air) and c is the velocity of sound in the medium (33,280 cm sec^{-1} for air), and provided these quantities may be regarded as constants, it follows that a sound pressure, P dyne cm^{-2} can be expressed in decibels as —

$$xdB = 20 \log_{10} \frac{P}{P_0}$$

where $P_0 = .0002$ dyne cm^{-2}

(xvi) **Subjective Loudness — The Phon**

While subjective loudness is based upon logarithmic sound level, it varies greatly with frequency, and this variation is dependent on the intensity itself.

The loudness of a sound that has the same subjective loudness as a 1000 Hz tone of intensity L watt cm^{-2} (or P dyne cm^{-2}) is expressed in Phons as —

$$x \text{ Phon} = 10 \log_{10} \frac{L}{L_0} \quad (\text{or } 20 \log_{10} \frac{P}{P_0})$$

where $L_0 = 10^{-16}$ watt cm^{-2} (or $P_0 = .0002$ dyne cm^{-2}) which is the threshold of hearing at 1000Hz.

5. Natural Logarithmic Units

(xvii) The **Neper** (N)

Some European countries use the Neper as the basic unit of signal level relativity. It is based on e, the natural logarithm base (rather than 10 for the decibel).

Thus two power levels P_1 and P_2 are related by x Nepers if —

$$xN = \tfrac{1}{2} \log_e \frac{P_1}{P_2}$$

This follows from the more basic definition relating voltages V_1 and V_2 (or currents) which correspond to P_1 and P_2 in identical impedances.

$$xN = \log_e \frac{V_1}{V_2}$$

Note: From the above definitions,

$$\frac{\text{volts}}{\text{reference volts}} = e^{x \text{ (Nepers)}} = 10^{d \text{ (decibels)}/20}$$

$$\text{Thus } x = \frac{d}{20} \log_e 10$$

or 1 Neper = 8.686 decibels

or 1 decibel = 0.115 Nepers

Notes: (a) In the same way that units such as dBm, dBmO, dBr are derived from the decibel, the units Nm, NmO, Nr, etc., may be derived from the Neper.

(b) The decineper, abbreviated dN and equal to one-tenth of a neper, is often used in the literature; units such as dNm, dNmO, are derived from the decineper in the same way as corresponding units are derived from the decibel.

6. Supplementary Information

(xviii) **The Zero Relative Level Point** for telephone speech is a 2-wire reference point in a transmission system at which standard talker volumes are said to exist.

Notes: (a) The location of this point was once the 2-wire trunk test board at a main trunk exchange, but with the growing complexity of the telephone network it has become more obscure. At present in the Australian Post Office network it may be regarded as being located at a 2-wire point in the vicinity of the 2-wire/4-wire terminating sets at a minor switching centre.

(b) An international operator (e.g. O.T.C.(A)) usually has no such point as this in its own stations and must relate the dBr levels on its systems to the zero relative level point in the national (e.g. Australian Post Office) system or to another derived reference point.
Relative levels must be set correctly otherwise the inland or international transmission systems are liable to overload or alternatively noise interference will be excessive.

(c) Various points may occur in any transmission system where the relative level is zero (e.g., at the centre point of the O.T.C.(A) gateway telephone exchange).

(d) In the United States, this point is referred to as Reference or Zero Transmission Level Point (**RTLP** or **OTLP**).

(xix) **A Test Level** corresponding to 1 milliwatt at a zero relative level point was once usual but there is now a general tendency to use — 10 dBm, so as to obviate certain overload problems.

Notes: (a) The British Standard Test Level is more rigorously defined as the absolute level at a point in a circuit when the origin is energised by means of a generator having a resistance of R ohms equal to the nominal impedance at the origin and an emf of

$$2\sqrt{R/1000} \text{ volts}$$

(b) Line-up Level is synonymous with test level.

7. Illustration

On the last page of this bulletin is a drawing, titled "Transmission Levels on a Typical International Connection", which illustrates some of the units defined above.

8. References

Bell Telephone — "Transmission Systems for Communications"

Lenkurt — The Lenkurt Demodulator (selected articles)

C.C.I.T.T. — Red Book, Volume III

A.P.O. — Engineering Instruction, Trans. & Line Systems 0 2010

Henney — Radio Engineering Handbook

British Standards — BS.204

9. Illustrative Example

Refer to the typical circuit configuration shown on the last page of this bulletin. Assuming that a matched 3 dB pad is inserted in the 2-wire part of a telephone connection adjacent to and on the inland side of the A.P.O. 2-wire/4-wire terminating set, and that echo suppressors are fitted on the international side of the gateway exchange (–2 dBr transmit, + 2 dBr receive) —

(a) What is the loss in the echo path between echo suppressor receive output and echo suppressor transmit input for a short or open circuit on the inland side of the pad?

....(10 dB)

(b) What is the echo level at echo suppressor transmit input for the same conditions as in (a) for test level (1 milliwatt) applied at the far end?

....(–6 dBmO)

(c) As for (a) but with echo suppressor on the inland side of the gateway exchange (+ 2 dBr trans., –2 dBr rec.).

....(2 dB)

(d) As for (b) but with echo suppressor on inland side of gateway exchange.

....(–6 dBmO)

(e) If the noise level in a 3 KHz channel at the echo suppressor receive output for case (a) above is –43 dBm, express the received noise level in pw/km weighted (1960 C.C.I.T.T.) at the point of zero relative level assuming the length of the connection is 20,000 km.

....(0.93 pw/km)

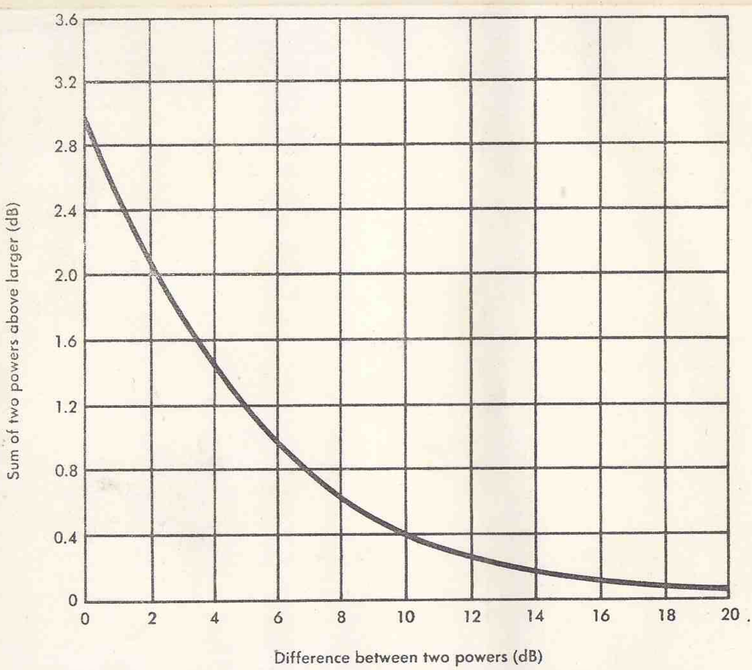
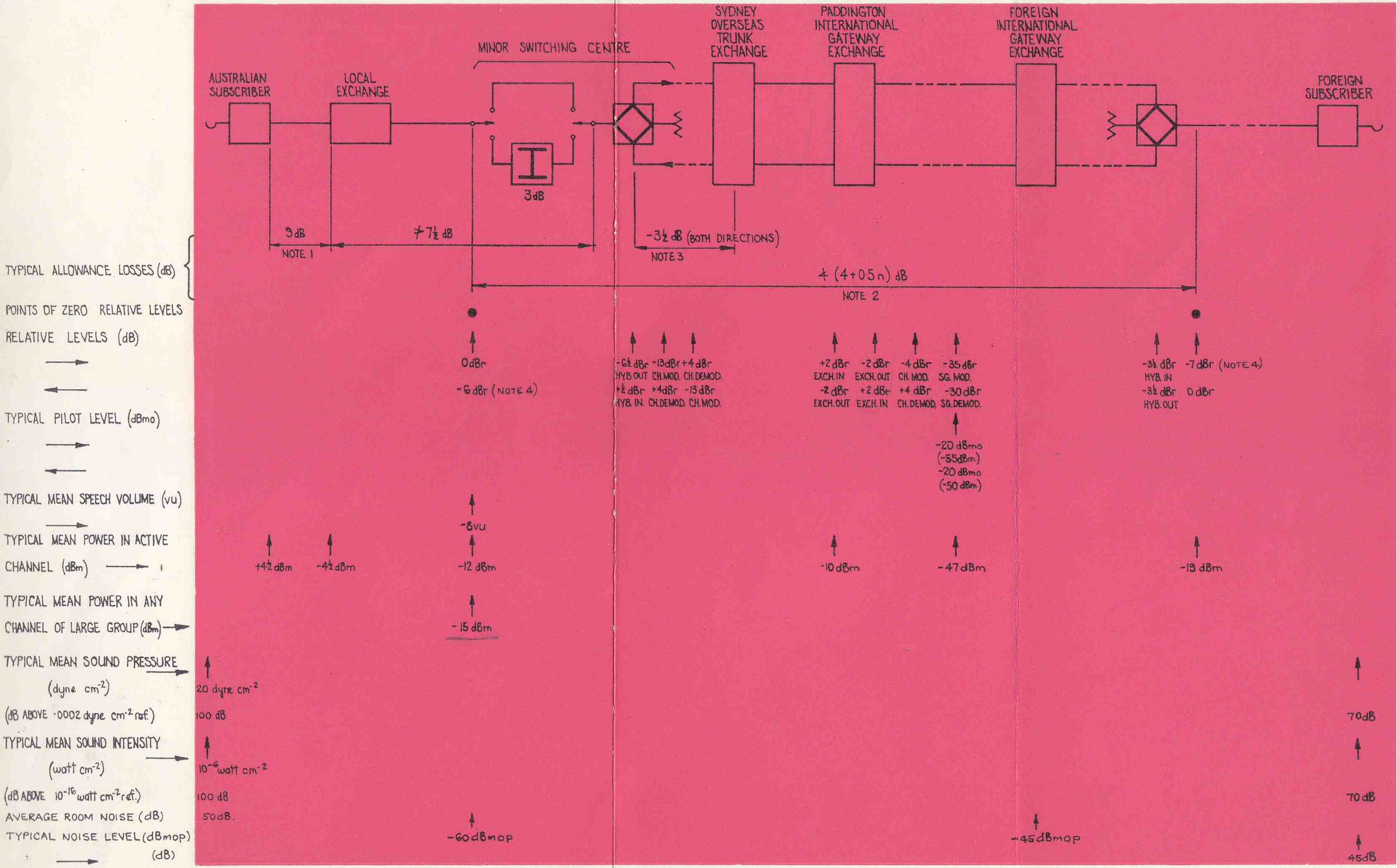


FIG. 2-8. Sum of two powers expressed in dB.

TRANSMISSION LEVELS ON A TYPICAL INTERNATIONAL CONNECTION



NOTES:
1. THIS IS THE LINE LOSS OF A TYPICAL LIMITING LENGTH OF SUBSCRIBER'S PLANT AND SHOULD NOT BE CONSTRUED AS ANY KIND OF LOCAL LINE TRANSMISSION LIMIT.
2. 'n' EQUALS THE NUMBER OF 4-WIRE SWITCHED, 4-WIRE CIRCUITS IN THE CONNECTION.
3. THE 2-WIRE TO 2-WIRE LOSS WOULD BE ZERO dB (PADS OUT), AND THE LOSS INTRODUCED BY THE LINK IN A 4-WIRE SWITCHED CONNECTION WOULD BE ZERO dB.
4. THESE RECEIVE LEVELS VARY ACCORDING TO THE TRANSMISSION PLAN USED BY THE VARIOUS ADMINISTRATIONS.