these curves and the large number of complex variables involved in deriving them may limit their usefulness for direct simulative synthesis. However, a number of generic features such as formant frequencies and rolloff effects appear consistently.

Two curves are presented for trumpet mf and violin mf. The dashed curves are derived from data recorded from a second player on a different instrument, and are presented to indicate variations to be expected from player to player. The vertical (intensity) separation of the curves for an instrument at the three different dynamic markings is derived from average intensity results reported previously [2].

A simple but versatile parametric "model" for describing spectrum and intensity changes is shown in Fig. 12. The observed spectral envelopes are approximated using two straight-line segments, the lower frequency segment giving a rolloff slope in decibels per octave and the high-frequency segment giving the cutoff slope in decibels per octave. The breakpoint frequency is the junction frequency of the two segments and gives the primary formant or corner frequency.

Fitting the straight-line segments to the spectral envelope curves was difficult for the oboe, English horn, and, to a lesser extent, the flute. Table I is a summary of the lower frequency rolloff rates R, the high-frequency cutoff rate C, the corner frequencies f_c for the pp envelopes, and the changes in these parameters in going from pp to ff.

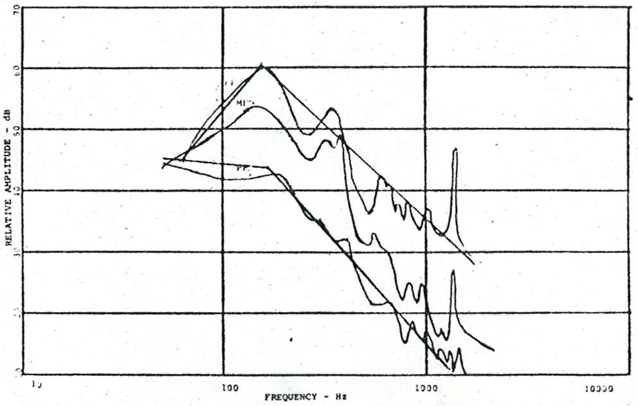

Fig. 10. Cello spectral envelope.

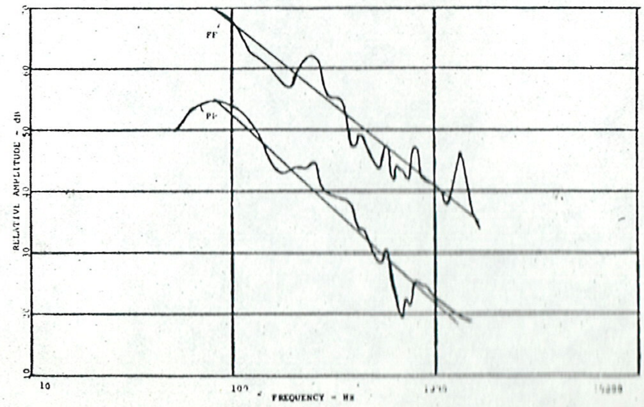

Fig. 11. Contra bass spectral envelope.

DISCUSSION

Trumpet

The trumpet exhibits a strong increase in high to low (above and below formant frequency of 1200 Hz) harmonic content. A pp note whose fundamental frequency is 300 Hz has a tenth-to-first partial intensity ratio at pp of about −25 dB and a ratio of about 0 dB for ff. In addition, in the transition from pp to ff, a distinctive formant at about 1200 Hz appears.

Trombone

The trombone has a greater initial cutoff slope than the trumpet, but shows a similar strong increase in the relative high/low harmonic content. The formant aspect again increases at increasing intensity.

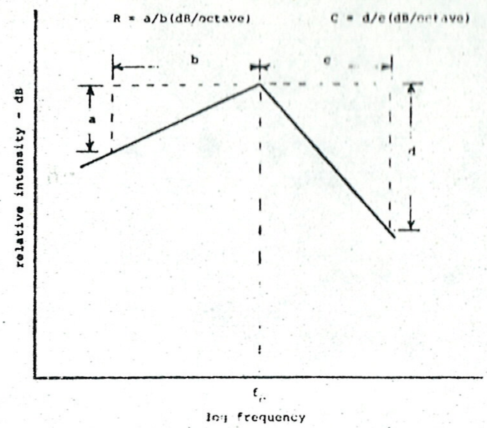

Fig. 12. Spectral envelope parameters.

Table 1. Spectral envelope model summary.

Instrument	Corner Frequency f_c (Hz) (pp)	Δf_c (pp–ff)	Rolloff R (pp) (dB/octave)	ΔR (pp–ff)	Cutoff c (pp) (dB/octave)	ΔC (pp–ff)
Trumpet	1200	0	0	4	15	− 8
Trombone	550	200	2	2	24	−10
French horn	550	0	2	3	20	0
Oboe	1300	0	3	0	17	− 3
English horn	900	*	*	*	11	*
Bassoon	520	0	4	−4	20	−11
Flute	780	130	−4	14	15	2
Violin	350	0	8	2	9	− 3
Viola	350	0	6	3	9	− 1
Cello	160	0	2	8	11	− 2
Bass	80	0	*	*	10	− 1

* Data do not allow reliable interpretation.

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French Horn

The horn is characterized by an increase in the strength of partials near the 550-Hz formant frequency. There appears to be little change in the high-frequency cutoff rate. It is interesting to note that the pp trombone is less bright then the horn, while the ff tombone is significantly brighter than the horn.

Oboe

The oboe is characterized by two formants at about 1200 and 3300 Hz. The primary change in the spectrum is an increase in the strength of partials near the upper formant.

English Horn

The English horn spectral envelope curves did not exhibit sufficient dynamic level differences to extract useful dynamic effects. The curves are shown for reference purposes.

Bassoon

The bassoon exhibits a strong formant at 500 Hz for the pp and mf scales. The ff scale is much flatter, with a secondary formant at about 1100 Hz becoming important. The model does not fit the actual bassoon curves well, and the rolloff characteristics of the mf scale are anomalous to the extent that the rolloff trends are not consistent from pp to mf and mf to ff.

Flute

The flute curves show a constant cutoff rate and a strongly increasing rolloff rate. In addition, as the intensity increases, a strong formant characteristic appears. The formant frequency increases with intensity, which results in a substantial increase in relative high-frequency content, even though the cutoff rate is approximately constant.

Violin and Viola

The violin and viola exhibit very similar rolloff and cutoff rates. The viola has a broad central formant, which is not approximated well by the model. Both the violin and viola show modest increases in rolloff rates and decreases in cutoff rates as the intensity increases, indicating a small but significant increase in relative high-frequency harmonic content as the intensity increases.

Cello and Bass

The cello and bass exhibit cutoff rates which are similar to the violin and viola, both in absolute magnitude and in the changes with intensity. The cello exhibits a marked increase in rolloff rate, to the extent that a formant characteristic is not present at pp while a strong formant characteristic developes at ff.

CONCLUSION

With one notable exception, the bassoon, all rolloff rates increased as intensity increased. Similarly with one exception, the flute, all cutoff rates decreased. Both of these effects reflect a relative increase in high-frequency conte[nt]. The increases in rolloff rates range from 14 to 0 dB [per] octave, while the decreases in cutoff rates cover the range [of] 11 to 0 dB per octave. Considering the wide range [of] variation with intensity and the wide range of initial r[oll]off rates (−4 to 8 dB per octave) and cutoff rates (9 to [..] dB per octave), it is clear that both variable center [fre]quency and variable slope filters would be useful for si[mu]lative synthesis.

In a number of cases (trumpet, trombone, horn, ob[oe,] flute) the ff scales are more formant dominated than the [pp] scales.

The stringed instrument results are very consistent. T[he] lower pitched the instrument, the lower the initial roll[off] rate, and the greater the difference in rolloff between pp a[nd] ff.

It is very difficult to set error limits on the values repor[ted] in Table I. It is felt that the trends in the rolloff and cut[off] rates as the intensity varies are reliable.

REFERENCES

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About the Author:

David A. Luce was born in 1936 in Youngstown, Ohio. He received the B.S. degree in physics from Case Institute of Technology in 1958 and Ph.D. in physics from the Massachusetts Institute of Technology in 1963.

He worked in research in musical acoustics and development of new musical instruments with Melville Clark Associates from 1964 to 1970, and is currently Vice President of Research and Development at Moog Music, Inc. Dr. Luce is a member of the Audio Engineering Society.

Editor's Note: It has been brought to our attention th[at] the major portion of the Project Note "Logarithmic Re[c]ord-Level Indicator" by Robert E. Berglas, which a[p]peared in our March 1975 issue, is material taken direct[ly] from "Logarithmic Converters" by Robert C. Dobki[n]. The article was originally published in November 19[..] by National Semiconductor Corporation and reproduce[d] in their Linear Applications (1972).

We very much regret that Mr. Dobkin and Nation[al] Semiconductor Corporation were not given credit for th[e] article, and we wish to thank the readers of the Journ[al] who brought this to our attention.