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Removal of Channelled Spectra Signatures in Fourier Spectroscopy

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Abstract

The presence of a plane, parallel-sided dielectric component in the optical path produces channelled spectra or signatures in conventional or Fourier transform spectroscopy respectively. These features are generally undesirable and a method of removing them based on scaling the zero path signature of the interferogram is described. Spectroscopic information concealed by the signatures is left intact. The method is applied to signatures arising from the diamond window of a Golay detector and the results presented for both the interferograms and the corresponding spectra.

1. Introduction

The presence of a plane, parallel-sided slab of dielectric in the optical path of either a conventional spectrometer or a Fourier transform spectrometer produces interference fringes (channelled spectra) or their signatures. These features are, in general, undesirable and such dielectric components are normally wedged to suppress their fringe patterns. For effective suppression, a good rule of thumb is that the wedge (over the larger dimension of the optical beam) should be sufficient to produce five localized fringes for the maximum wavelength in use.

It is not always possible or desirable, however, to wedge components. For example, a sample may need to be parallel sided for precision measurement of its absorption spectrum, or it may be too thin to be suitably wedged. It is therefore useful to have some method for removing channelled features from the spectrum, or interferogram, itself. Several such methods have been proposed. The first of these (Hirschfeld and Mantz 1976) was developed to eliminate the signature of the channelled spectrum obtained by the use of a Michelson-type Fourier transform spectrometer. If n and d are the refractive index and thickness respectively of the offending dielectric slab, the interferogram contains signatures spaced at intervals of $2nd$ (Russell and Bell 1967). In one of the methods described by Hirschfeld and Mantz, the interferogram is first measured with the sample normal to the beam of radiation and then remeasured with a slight rotation of the sample to present a different sample thickness to the beam. By replacing the data points of the signature in the first interferogram with data points at the same mirror location from the second (in which the signature has been displaced), a composite interferogram is obtained which, on Fourier transformation, produces no fringe pattern. The feasibility of this method depends upon how localized the signature is and how much rotation of the sample is possible.

A second method (Clark and Moffatt 1978) modifies the spectrum itself. A computer is used to subtract a cosine term from the spectrum and to adjust several parameters until the best visual result is obtained. The deficiency of this technique is that it is an interactive one in which data are optimized by human judgment based on an *a priori* assumption about the appearance of the spectrum.

A third method, used occasionally by the present authors (see also Hirschfeld and Mantz 1976), is to simply replace the region of the interferogram signature with data points equal in value to those at a very large path difference. This is a reasonable technique only if the value of $2nd$ is sufficiently large so that the signatures occur in regions where the interferogram has already reached an almost constant value. In this method, the information concealed by the signature is, of course, lost.

In the present paper, a fourth method is presented. It essentially involves subtracting the scaled zero path difference signature ('grand signature') in an interferogram from those which occur at intervals of $2nd$. The basis for this is given in the next section.

2. Theory

A collimated electromagnetic wave normally incident on a plane parallel transparent slab has a transmitted amplitude $A(\sigma)$ given by

$$A(\sigma) = TA_0(\sigma)(1 + Re^{i\delta} + R^2e^{2i\delta} + R^3e^{3i\delta} + ...) \tag{1}$$

(see e.g. Jenkins and White 1976). Here σ is the wavenumber, T and R are the transmittance and reflectance of the slab, $A_0(\sigma)$ is the incident amplitude, and $\delta = 4\pi\sigma nd\cos\theta'$ where θ' is the angle of refraction for an angle of incidence θ.

It has been shown (Randall and Rawcliffe 1967) that the intensity of the transmitted radiation is given by

$$B(\sigma) = \{(1-R)/(1+R)\}B_0(\sigma)(1 + 2R\cos\delta + 2R^2\cos 2\delta + 2R^3\cos 3\delta + ...), \tag{2}$$

where $B_0(\sigma)$ is the spectral intensity without the dielectric slab. If this radiation is now passed through a Michelson interferometer and the movable mirror scanned, the resultant interferogram will have an intensity variation with optical path difference x given by (Grant 1980)

$$\begin{aligned} I(x) &= \int_{-\infty}^{\infty} B(\sigma)\,e^{2\pi i\sigma x}\,d\sigma \\ &= \{(1-R)/(1+R)\}\left(\int_{-\infty}^{\infty} B_0(\sigma)\,e^{2\pi i\sigma x}\,d\sigma + 2R\int_{-\infty}^{\infty} B_0(\sigma)\cos\delta\,e^{2\pi i\sigma x}\,d\sigma \right. \\ &\qquad \left. + 2R^2\int_{-\infty}^{\infty} B_0(\sigma)\cos 2\delta\,e^{2\pi i\sigma x}\,d\sigma + ...\right) \end{aligned}$$

for a non-dispersive medium. After some manipulation it can be shown that

$$I(x) = \{(1-R)/(1+R)\}\left(I_0(x) + \sum_{m=1}^{\infty} R^m\{I_0(x+2mnd) + I_0(x-2mnd)\}\right), \tag{3}$$

where

$$I_0(x) \equiv \int_{-\infty}^{\infty} B_0(\sigma)\,e^{2\pi i\sigma x}\,d\sigma$$

is the intensity variation of the interferogram without the slab (see Russell and Bell 1967; Randall and Rawcliffe 1967; Grant 1980). Thus, the presence of the dielectric plate results in an overall reduction of the intensity of the interferogram by the factor $(1-R)/(1+R)$ and the presence of signatures (Russell and Bell 1967) at intervals of $2nd$ on either side of the grand maximum, the latter occurring at $x = 0$. These signatures are scaled *reproductions* of $I_0(x)$ each having a magnitude which differs by the factor R from that of the one adjacent to it.

If the signatures are such as to produce little distortion of the grand signature then they can be removed by scaling the latter appropriately and subtracting the result from each signature. In principle, of course, the ratio of the peak heights of the first signature ($m = 1$ in equation 3) and the grand maximum should yield R, the reflectivity of the offending dielectric slab. In practice, however, the radiation is not usually collimated and the dielectric may be absorbing or have nonparallel surfaces. Thus, even if R is known, its use as a scaling factor is not very reliable. It might be noted that when the radiation converges onto the slab, the signatures are spaced by intervals of $(1+\cos\theta'_m)nd$ (Randall and Rawcliffe 1967), not $2nd$ as described above. Here θ'_m is the angular size of the converging cone of radiation after it enters the slab.

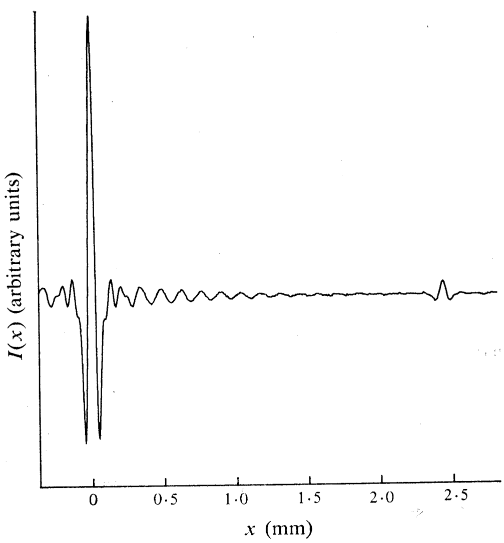


Fig. 1. Range 3 interferogram showing the first order signature at a path difference x of 2·445 mm.

The effect of the dispersive character of the dielectric slab will become more pronounced as the spectral range of radiation forming the interferogram is increased. This is somewhat difficult to incorporate analytically. If the spectral range is one over which Cauchy's formula holds, that is, $n(\sigma) = N + A\sigma^2$, where N and A are constants, then dispersion can be included via the reflectivity, assuming no absorption and that $A\sigma^2 \ll N$. After some algebra (Grant 1980), the resulting interferogram again is found to have signatures, these being spaced at intervals of $2Nd$ on either side of the grand maximum (for a collimated beam). In this case, however, the signatures are not just scaled reproductions of the grand maximum pattern but involve its derivatives. In the following analysis, dispersion has not been taken into account.

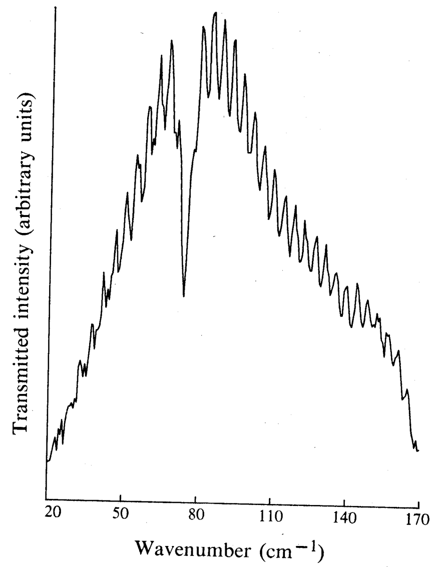


Fig. 2. Spectrum corresponding to Fig. 1. The broad absorption line near 74 cm^{-1} is due to a high density polythene window.

3. Experiment

The interferometer used was a Polytec FIR25. As supplied this instrument has four selectable frequency ranges, covering the regions (1) 100–800 cm^{-1}, (2) 50–500 cm^{-1}, (3) 20–180 cm^{-1} and (4) 10–55 cm^{-1}. Fig. 1 shows the range 3 interferogram for a mirror scan to just beyond the first signature, $m = 1$, of equation (3). Fig. 2 shows the transform of the interferogram of Fig. 1, thus revealing the fringe pattern corresponding to the $m = 1$ signature.

The procedure used to remove the signature is straightforward. The interferometric data is collected digitally and a parabolic fit made to the three data points closest to the grand maximum. A similar procedure is adopted for the signature maximum. This gives values for the intensities I_{gm} and I_{sm} of these two features and permits a value of $2nd$ to be determined with precision. An estimate is now made of the extent of the signature and hence the number of data points involved. Interpolated values $I(x)$ of these points in the grand signature are reduced by the factor I_{sm}/I_{gm} and subtracted from the corresponding values $I(x+2nd)$ in the signature. Fig. 3 shows the corrected interferogram for the data of Fig. 1. In Fig. 3, the lower solid curve gives that region of $I(x)$ in the immediate vicinity of the first signature ($m = 1$), while the dashed curve represents the scaled grand signature shifted so that its maximum coincides with that of the first signature. The scaling factor obtained here was 0·0433. The upper part of the figure gives this portion of the interferogram after the correction has been made. The transform of the full interferogram is given in Fig. 4 and demonstrates the effectiveness of the method. Fig. 5 shows the ratio of the data of Fig. 2 to those of Fig. 4, thus essentially displaying the interference fringe pattern free of the instrumental background.

Similar results to those shown in Figs 1–5 were obtained for the other three spectral ranges showing that dispersion effects are negligible. In the case of range 4, the noise tended to conceal the fringe pattern so that, visually, the spectra equivalent to Figs 2 and 4 are very similar. Nevertheless, the ratio of these two spectra shows a clear interference fringe pattern which, within the experimental error, has spacings the same as those expected from $2nd$.

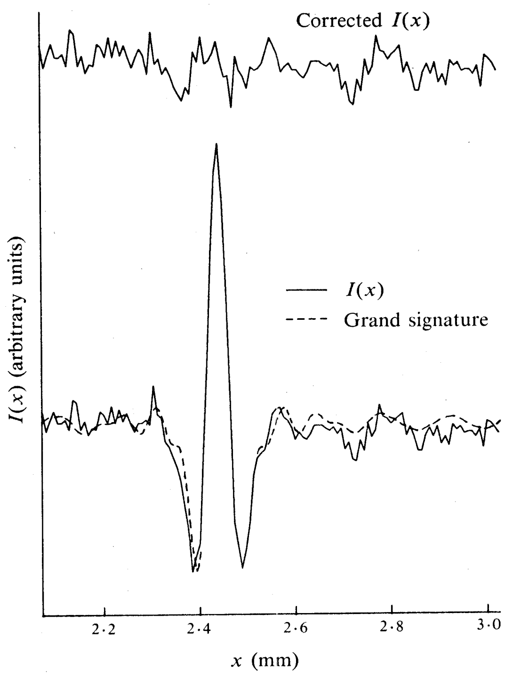
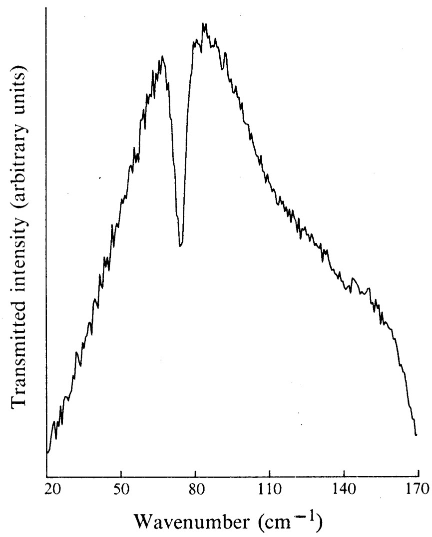


Fig. 3. Interferogram of Fig 1 in the region of the $m = 1$ signature. The scaled and shifted grand signature is shown superimposed for comparison (dashed curve). Subtraction of the dashed from the solid curve gives the corrected data shown in the upper part of the figure which has been shifted and expanded in $I(x)$ for clarity.

Fig. 4. Spectrum corresponding to the full interferogram, corrected as shown in Fig. 3.



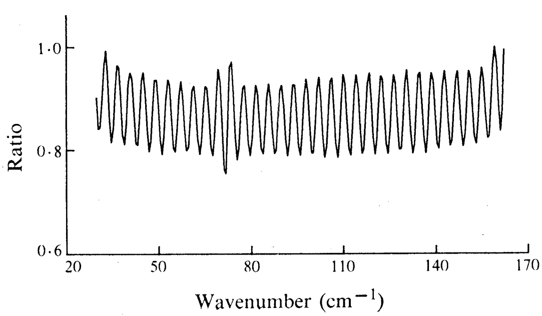


Fig. 5. Ratio of spectrum shown in Fig. 2 to that of Fig. 4. The data have been normalized to give a maximum of 1.

The origin of the signature described above was finally attributed to the diamond window of the Golay detector. The relative size of the signature was found to vary with the position of the Golay detector and to increase as the source aperture was decreased (apparent reflectivities of up to 10% were observed with a 1 mm source aperture). It seems likely that a small 'flat spot' on the diamond window was responsible. This would account for the discrepancy between the calculated reflectivity of 17% for diamond and the apparent reflectivity of 4·3% shown in Fig. 1. The average value obtained for $2nd$ over all spectral ranges was 2·445 mm ($\pm 8\ \mu$m). For a value of $n = 2 \cdot 39$ (Breckenridge *et al.* 1974) the thickness d of the area responsible for the signature is 0·512 mm.

4. Conclusions

It has been demonstrated that the method of using a scaled grand signature to remove channelled spectra signatures is particularly effective in this case. Apart from the need to make a decision regarding the range of x over which the signature is significant, the method is completely objective. The same technique can be used, of course, to eliminate the fringe pattern from a spectrum obtained in the conventional way. After collecting the data digitally it is Fourier transformed, the signature deleted in the manner described above and the 'interferogram' transformed back to the wavenumber domain.

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