AM Companding: Reducing the Power Consumption of LF and MF Transmitters

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Abstract
AMC, or AM companding, is currently used on all high-power BBC LF and MF transmitters to reduce electricity consumption. The BBC-designed equipment carrying out the companding is the AM6/34A. In essence, AMC system reduces the carrier power at high modulation levels, the argument being that the modulation will then mask any increase in background noise and interference. As a bonus, the AGC system in the receiver will tend to compensate for the changes in carrier level, hence making the overall system more transparent. At present, companding of 3 dB is applied.

With the BBC anxious to cut costs and establish its Green credentials, the hope was to increase the companding to 6 dB. Hence a joint project was set up between the BBC and Arqiva (the transmission providers) to evaluate the feasibility of this, using a combination of laboratory tests and field measurements. The field measurements involved the transmitters at Washford and Droitwich. This report describes the work carried out.

The important conclusions are as follows:
❖ The existing AMC system introduces appreciable distortion artefacts because of its very short attack time. This distortion becomes worse as the amount of AMC increases.
❖ The distortion artefacts can be rendered negligible by lengthening the attack time, and 50 ms is recommended in this report. The effect on electricity consumption is negligible.
❖ Although the longer attack time causes the transmitter power to overshoot during the attack, no harm results; in fact, the effect on system performance is beneficial.
❖ When background noise is present at a level equivalent to that at the edge of the service area, the degradation introduced by 6 dB companding corresponds to a loss in transmitter power of less than 1 dB, and is negligible in practice.
❖ Extensive field-survey measurements of both sound quality and field-strength confirm that the increase in AMC does not have any detectable ill-effects.
❖ The long-term measurements made at Droitwich indicated electricity savings of £86k for the Radio 5 transmitters alone, and £155k if the transmitters for Radios Ulster, Scotland and Wales were to be included. This assumes an electricity cost of 10p per unit.
❖ Although worthwhile, the above savings are rather less than predicted from the laboratory work and the initial trial at Washford. The differing programme content could be a factor. It is also possible that a change in transmitter alignment could retrieve part of the loss.

Modifying the AM6/34A Compander is straightforward. The amount of companding is set by means of an internal handbag link, and the increase in attack time involves adding two capacitors. The Compander already has provision for these components.
White Papers are distributed freely on request.

Authorisation of the Chief Scientist or General Manager is required for publication.
AM Companding: Reducing the Power Consumption of LF and MF Transmitters
Ranulph Poole (BBC R&D) and Phil Kesby (Arqiva)

1. Introduction and Background
AM Companding, or AMC, is a technique employed with AM broadcast transmitters to save electricity costs. The idea is a simple one: at low modulation levels — ‘the quiet passages’ — the transmitter behaves normally and transmits the same power as it would do in the absence of AMC. However, as the modulation level increases, the carrier power is progressively decreased whilst retaining the original modulation depth. At high modulation levels, the programme material stands a good chance of masking any increase in background noise and interference. Because the automatic gain control (AGC) within the receiver will tend to compensate for the changing carrier power, the overall system can be made notionally transparent.

At present, Radio 5 Live is transmitted on MF from ten 50 kW transmitters at five separate sites. AMC is applied to these at a level of 3 dB carrier compression. The BBC wishes to save electricity costs still further, at the same time enhancing its ‘Green’ credentials. To that end, it is taking part in a combined project with Arqiva, the transmission providers, to establish whether an increase to 6 dB compression is feasible. The estimated cost saving would be £86k per annum. Although these were not originally under consideration, there are further eight transmitters associated with Radios Scotland, Ulster and Wales. Including these within the scheme would give a cost saving of about £155k per annum — or £1.5M over ten years.

This White Paper describes the contributions of both the BBC and Arqiva to the present project — ‘present’, since the BBC carried out considerable work in the 1980s. [1] and [2]. Despite the thoroughness of this earlier work, the subject needs revisiting because of changes that have happened in the meantime. In particular, the possible power savings could be different with modern programme material and revised audio compression techniques. There could also be a benefit in changing the time-constants associated with the companding process.

2. The Transmitters and the AMC Process
The transmitters concerned employ a technique known as Doherty modulation. To over-simplify somewhat, a single vacuum tube — the ‘carrier valve’ — provides the carrier and negative-going modulation, whereas a second tube — the ‘peaking valve’ — adds on the positive-going modulation. A block diagram of the transmitter is given in Figure 7 of [1], and a short description appears in Appendix 3. As these references make clear, the peaking valve does more than simply providing extra power when it is needed: it also impedance-modulates the load seen by the carrier valve. However, as far as the application of AMC is concerned, the important point is that the carrier level can be controlled by means of the DC component of the modulation.

Each transmitter is driven from a BBC-designed audio compander, coded AM6/34A. There are two outputs from this — one for the carrier valve and one for the peaking valve. These are DC coupled for the reason already given. A block diagram is shown in Figure 6 of [2] and, as for the transmitter, Appendix 3 gives an outline of its workings. The implementation boasts ‘digital signal processing techniques’, but is still basically analogue in concept; the digital circuitry is restricted to providing the necessary signal-path delays.

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1 There are further large Radio 5 transmitters at Brookmans Park, Start Point and Clevedon, but these are not under consideration here.
2 Audio compressors are used to keep the modulation depth high, and to give the broadcast the ‘right sound’. Do not confuse audio compression with AMC!
3 The description refers to the earlier AM6/30, but the circuitry is identical in all important respects.
Some details of the AM6/34A will be repeated here, as the various time-constants and so forth are important to the performance of the overall transmitter–receiver system. To provide a control voltage, the instantaneous peak level of the incoming signal is measured, and the result is passed through a low-pass filter to give the required attack time. A simple RC time-constant then determines the decay time. The filtered control voltage is processed in such a way that it remains constant for audio levels corresponding to a maximum of 10% AM; thereafter it decreases linearly with the audio level. For 6 dB companding, the control voltage is half its initial value when the AM reaches 100%.

This control voltage sets the level of the audio fed to the transmitter. The AM6/34A performs the task in a neat way by using the control voltage as the reference of a digital-to-analogue converter (DAC), in effect giving a perfect multiplier. As the carrier level of the transmitter has to be reduced in the same proportion as the audio, the control voltage is added into the audio. The combined signal is then DC-coupled within the transmitter as far as the modulator.

If the transmitter power is not to overshoot during the attack period, the audio needs to be delayed in advance of the gain-control element (the above DAC). In that way, when an audio peak arrives at the gain-control element, the control voltage has already achieved the gain reduction required. As will be seen, it is arguable whether removing the overshoots is necessarily a worthwhile aim.

It seems that the attack and decay times were set at an early stage of the initial work. The first report [1] states that ‘in practice an attack time of 0.3 ms and recovery time option of some 125 ms to 250 ms were provided in the experimental equipment first constructed.’ This statement is repeated nearly verbatim in [2]. [1] also states that the time-constant of the AGC ‘in the receivers examined’ was around 20 ms — something that accords with the author’s experience. Although the longish recovery time-constant is uncontroversial, the short attack time is more surprising. Both reports say that ‘use of a shorter attack time increases the risk of quality impairment due to over-rapid control, while an increase would either lengthen the period of overshoot in a simple control arrangement, or demand an increase in audio signal delay time in the non-overshoot input-controlled arrangement…’

It would seem reasonable to revisit the attack time. Conventional wisdom says that values greater than about 5 ms are needed to avoid audible distortion, and it is interesting that the AM6/34A originally provided a 6 ms option. Increasing the attack time further to around 20 ms would give the receiver AGC a chance to track the changes in carrier level more precisely, hence improving the system transparency. Needless to say, the change in companding from 3 to 6 dB would make any distortion associated with the companding process more troublesome.

3. Initial Preparations and Tests
The aim was to carry out initial measurements and listening tests at BBC R&D under at least partly controlled conditions. Importing a 50 kW transmitter was obviously not an option. An ‘AMC Comparison Unit’ was therefore built. This included a ‘transmitter’ — a double-balanced modulator, with a direct-coupled audio input suitable for interfacing with the AM6/34A. The carrier for the transmitter would be provided by an external signal generator.

The AMC Comparison Unit also possessed an idealised ‘receiver’ — essentially a gain-controlled amplifier and precision rectifier. The AGC had a selectable time-constant of between 1 ms and 1 s, so that the effect of the AGC time-constant on the success of the AMC system could be established. A low-pass filter restricted the audio bandwidth to 4.5 kHz at –6 dB.

The original idea was to use the AMC Comparison Unit with a ‘real’ AM6/34A, and this was done during the initial tests. However, for experimental purposes, it proved more convenient to build an ‘AMC Simulator Unit’ — a stripped-down version of the AM6/34A. The Simulator was carefully checked to ensure that its characteristics matched those of a ‘proper’ AM6/34A. The only slight challenge was the audio delay-line. It was possible to implement the ‘official’ 0.3 ms delay with an analogue all-pass network in place of the rather complicated digital circuitry. However, the 6 ms option was impracticable.
Samples of programme material were provided by the Radio 5 Live studios, in the form of .wav files, both before and after audio processing. (Processing is normally carried out at the transmitting station, but the studios also possess a processor that can be used to replicate the transmitted ‘sound’. ) In addition, Arqiva recorded some different programme material at the transmitting station itself.

Initial, informal listening tests were carried out in the presence of BBC and Arqiva staff. The set-up is illustrated below, and the picture is largely self-explanatory. As well as the receiver built into the AMC Comparison Unit, a portable radio and a car radio were available.

![Set-up for the Initial Listening Tests](image)

**Figure 3.1:** Set-up for the Initial Listening Tests

The general impressions were as follows:

- The sound quality of the programme material after audio processing was not greatly liked, but there was little evidence that moving between 3 and 6 dB AMC made an appreciable difference.
- The presence of AMC was most noticeable on a sample of speech containing appreciable gaps. The sudden reduction in transmitter carrier power at the start of each burst of speech caused an audible ‘thump’ at the output of the receiver. This was particularly true where the loudspeaker had an extended bass response.
- When noise was added to the signal at the input to the receiver, as might be present at the edge of the transmitter’s service area, the noise pumping caused by the AMC was not deemed objectionable. Sometimes the noise was felt to mask the AMC artefacts.

The conclusion was that it would be worth continuing with the investigation.

4. **The Effect of AMC on Transmitter Power Consumption**

Before looking into the effect of increased compression on received signal quality, there were two important questions to answer:

- What saving in power consumption can be expected? — or, rather, is the saving significant in comparison with that originally achieved by the introduction of AMC?
- If the transmitter power is allowed to overshoot because of a longer attack time, will that have an adverse effect on power consumption?

To find out, a simple power meter was made, which could be driven from the transmitter output of the Comparison Unit. It comprised a voltage-squaring device followed by an integrator. An audio sample could then be played through the system and the average transmitted power measured for the different AMC settings. When translating the results into the real world, it has to be assumed that the power consumption (from the mains) is roughly proportional to the transmitted power.

Details of the ten audio samples are given in Appendix 1. For the most part, the samples are 2–3 minutes long, but two last for around 7 minutes. Together, they represent a fair cross-section of Radio 5’s output.
Some results are illustrated below for the original short attack time (and no overshoots). Each vertical line represents an audio sample, and the colour-coding is that given in Appendix 1.

![Graph showing relative average powers](image)

**Figure 4.1:** Relative Average Powers: No Audio Processing, No Overshoots

![Graph showing relative average powers](image)

**Figure 4.2:** Relative Average Powers: Audio Processing, No Overshoots

The most obvious feature of these results is the effect of the audio processing. Without the processing, the average modulation level is low and the AMC is not very helpful: there is considerable overlap between the ‘3 dB’ and ‘6 dB’ results. Introducing the processor actually increases the power consumption slightly in the absence of AMC, but, when introduced, the AMC is then very effective. The indications are that AMC at 3 dB and 6 dB saves around 40% and 60% respectively.

To see the effect of overshoots on power consumption, the exercise was repeated with the AMC attack time first at 20 ms and then at 50 ms. The results for AMC at 6 dB are shown overleaf. Audio processing was used throughout.

Comparison of Figures 4.3 and 4.2 shows that the presence of 20 ms overshoots makes no discernible difference to the power consumption, and the difference is still very small when the attack time is extended to 50 ms: the savings for AMC without and with overshoots are 58.8% and 58.0% respectively.
It has been tacitly assumed that the transmitters are capable of handling the overshoots caused by the long attack time. That is certainly true of the 50 kW transmitters in question: they were designed to provide the full 50 kW continuously, and Arqiva confirm that alignment is carried out at full power. AMC with overshoots is not asking any special favours of the transmitters!

As pointed out earlier, the overshoots improve the system transparency. This is perhaps not intuitively obvious, but a moment’s thought shows that the system will be transparent provided that any change in carrier level is slow enough for the AGC in the receiver to track it fully. With AMC as currently used, a burst of high level audio causes the transmitter power to fall before the AGC has had a chance to respond. The output of the receiver will therefore be too low during the attack period. Some simulated waveforms are shown in Appendix 2.

5. **The Effect of AMC on Sound Quality**

So far, an increase in AMC is looking promising. However, the important question now is what happens to the sound quality. It was appreciated that the effects of AMC could be quite subtle, and so a method had to be devised to exaggerate them. Without that, it would be difficult to tell whether a change in compression or attack time settings had really made a difference.

The tactic adopted is shown overleaf. It relies on two Simulator/Comparison Unit pairs, identical apart from the settings. These feed the two inputs of a difference amplifier. There will be no output from the amplifier if the Simulator/Comparison Unit pairs are set up identically. However, if one is ‘clean’, then the distortion products from the other will emerge.

For listening tests, the differential amplifier can be unbalanced so that the undistorted component of the audio is not cancelled completely. For the tests to be described, the distortion was enhanced by about 16 dB so that it was clearly audible. There was then no need for experienced listeners or a carefully controlled listening environment.
An indication of the damage done by a short attack time is illustrated below. The lowermost (blue) trace is the original programme material — about 2 seconds’ worth. The middle trace shows the distortion products caused by the rapid changes in carrier level: the positive-going spikes cause the ‘thumps’ mentioned earlier. The upper trace shows the benefit of slowing the attack to 20 ms — the effect would have been even more dramatic with the full 50 ms.

A panel of ten volunteers was assembled to assess the audible effect of changing the amount of AMC and the attack time. The volunteers were a random selection, with none being a trained listener. Three clips of ‘real’, processed programme material were used, as listed below.

<table>
<thead>
<tr>
<th>Clip No.</th>
<th>File Name</th>
<th>Start/Finish Times</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Jerusalem orchestra</td>
<td>00–28 seconds</td>
<td>Speech, mainly female.</td>
</tr>
<tr>
<td>2</td>
<td>Jerusalem orchestra</td>
<td>28–60 seconds</td>
<td>Soprano singing ‘Jerusalem’ to a string quartet accompaniment. ‘Critical’ material.</td>
</tr>
<tr>
<td>3</td>
<td>NEW fighting talk</td>
<td>00–45 seconds</td>
<td>Animated male speech with superimposed jingle.</td>
</tr>
</tbody>
</table>

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<td>00–45 seconds</td>
<td>Animated male speech with superimposed jingle.</td>
</tr>
</tbody>
</table>

**Table 5.1:** Programme Material Clips Used for the Listening Tests

Each clip was played 5 times, in random order, as follows:

- Without AMC.
- With 3 dB AMC and attack times of 0.3 ms and 20 ms.
- With 6 dB AMC and attack times of 0.3 ms and 20 ms.

**Figure 5.1:** Comparison of AMC Systems with a Differential Amplifier

**Figure 5.2:** Distortion Introduced by AMC System with Short Time-Constant
At the start of each group of five samples, the undistorted clip was played as a reference. Each volunteer was then asked to rate each sample according to the standard 5-point ITU-R impairment scale [3], with 5 being ‘imperceptible’ and 1 being ‘very annoying’. Although not sanctioned by [3], a score of zero was allowed for sound that was deemed unusable. Fractional scores were also allowed.

A small laboratory was used in place of a certified listening room, partly because it was felt that the tests should be carried out in something more akin to a domestic environment. The loudspeaker was a compact, medium-quality model.

![Image](image-url)

**Figure 5.3:** Results of the Listening Tests for 0.3 ms and 20ms Attack Times

The results are given above, where each volunteer has been allocated a different colour. There were some differences between the results for the three clips, and the average values are shown. The averages across all volunteers are as follows:

<table>
<thead>
<tr>
<th>Overall Averages</th>
<th>3 dB</th>
<th>6 dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perfect</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td>0.3 ms</td>
<td>1.9</td>
<td>1.0</td>
</tr>
<tr>
<td>20 ms</td>
<td></td>
<td>1.9</td>
</tr>
<tr>
<td>0.3 ms</td>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>20 ms</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 5.3:** Average Impairment Scores

The benefit of a longer attack time is clear to see. With 3 dB AMC, the impairment associated with 20 ms attack is only just noticeable, whilst 0.3 ms attack causes very distressing distortion. When the AMC is increased to 6 dB, the longer attack time gives less of an improvement but is still worthwhile: it ensures that the sound quality is no worse than it was originally with 3 dB.

Two distortion mechanisms were obvious during the tests. With the short attack, the main effect was unpleasant cracks and bangs caused by the spikes illustrated in Figure 5.2. With the longer attack, these ‘non-linear’ artefacts were completely unnoticeable, but ‘wobbles’ in the level could be heard instead. These were due to the receiver AGC being unable to follow the carrier level changes fully. Perhaps there would be an advantage in an even longer attack time?

To find out, the attack time was increased to a nominal 50 ms, and the listening tests repeated with the same volunteers. As described in Section 4, it had already been established that the difference in transmitter power consumption would be minimal. The results, as given overleaf, show that the impairment score has improved by 1.7 to 3.6 for 6 dB AMC. Many listeners would find such sound quality acceptable. In contrast, the original system achieved an ‘annoying’ score of 1.9 for only 3 dB AMC. In the real world, without the distortion enhancement used during these tests, the impairments introduced by the improved system would be completely inaudible.
The work just described has shown that a simple change to the AMC system can reduce impairments to a negligible level, even with the compression increased from 3 to 6 dB. However, we still need to check that the system is satisfactory under less-than-ideal reception conditions, for instance when background noise is present at the edge of the service area. After all, the whole purpose of companding is to allay the effects of such noise!

To do this, the AMC Simulator and the AMC Comparison Unit were set up in the usual way, with 50 ms attack time and 20 ms AGC time-constant. Gaussian noise was then added to the ‘Interferer Input’ of the Comparison Unit as illustrated below. Its level was set to give –28 dBq, reference 100% AM, at the receiver output, with Rec. 468 weighting. This is equivalent to what might be expected at the edge of the service area, and is clearly audible.

Justification for this comment appears overleaf, where the listening tests show that noise at –28 dBq gives rise to an impairment score of about 4 — ‘perceptible but not objectionable’.

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**Figure 6.1:** Set-up for Assessing the Effect of Noise on AMC

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**Table 5.4:** Average Impairment Scores (Red) and Improvements over Previous Scores (Blue)

<table>
<thead>
<tr>
<th>Overall Averages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

---

6. **The Effect of AMC at the Edge of Service Area**

The work just described has shown that a simple change to the AMC system can reduce impairments to a negligible level, even with the compression increased from 3 to 6 dB. However, we still need to check that the system is satisfactory under less-than-ideal reception conditions, for instance when background noise is present at the edge of the service area. After all, the whole purpose of companding is to allay the effects of such noise!

To do this, the AMC Simulator and the AMC Comparison Unit were set up in the usual way, with 50 ms attack time and 20 ms AGC time-constant. Gaussian noise was then added to the ‘Interferer Input’ of the Comparison Unit as illustrated below. Its level was set to give –28 dBq, reference 100% AM, at the receiver output, with Rec. 468 weighting. This is equivalent to what might be expected at the edge of the service area, and is clearly audible.

Justification for this comment appears overleaf, where the listening tests show that noise at –28 dBq gives rise to an impairment score of about 4 — ‘perceptible but not objectionable’.

---

**Figure 5.4:** Results of the Listening Tests for 0.3 ms and 50 ms Attack Times
Listening tests were carried out with the same panel of volunteers and the same three clips of programme material as before. Four AMC settings — 0, 3, 6 and 9 dB — were used. If the AMC were to be totally transparent, the impairment scores would be the same for all settings. In practice, AMC causes the noise level to ‘breathe’ — an effect that becomes more objectionable the greater the AMC setting.

The listening tests also included a simple reduction in transmitter power of 6 dB, so that the noise level at the output of the receiver was –22 dBq. One would then hope for significantly worse sound quality than for 6 dB AMC. If that were not the case, AMC would have been shown to be a waste of time, and one might just as well turn down the transmitter power permanently!

The results of the listening tests are shown below:

![Figure 6.2: The Results of the Listening Test with Added Noise](image)

<table>
<thead>
<tr>
<th>Overall Averages</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 dB</td>
</tr>
<tr>
<td>3.8</td>
</tr>
</tbody>
</table>

Table 6.1: Average Impairments for the Above Listening Tests

There is no evidence from the results that degradations such as noise-pumping are audible with ‘normal’ noise levels and a maximum of 6 dB AMC. During the tests, pumping could be heard at 9 dB, but not excessively so. With large amounts of AMC and high levels of noise, the pumping was obvious as a ‘swishing’ sound. It was useful to let the panel of volunteers hear this effect so that they knew what to listen for with the subtler and more realistic tests.

Increasing the noise by 6 dB, without companding, causes a significant loss of sound quality — as expected.

7. **Equivalent Reduction in Transmitter Power**

The work just described has shown that the effect of AMC is largely benign in comparison with a reduction in transmitter power. However, it is still useful to have a figure for the equivalent reduction in transmitter power associated with a given amount of AMC. Planning tools exist that can then predict any loss of service area.

5 In fact, the added noise level was increased by 6 dB whilst maintaining a constant transmitter power. Since the receiver itself was noiseless, the effect was identical.
To obtain the relationship between AMC and equivalent power reduction, the test set-up illustrated in Figure 6.1 was used again. A fixed amount of noise was introduced, and listening tests were conducted with the variable being, first, the transmitter power and, second, the amount of AMC. A larger listening panel of 15 took part, and a good quality loudspeaker was used in a quiet environment.

The results for noise at $-30$ dBq — approximately what would be hoped for at the edge of the service area — are shown below. To prevent the charts from appearing too cluttered, only the scores of the first 10 listeners are given.

![Figure 7.1](image1.png)

**Figure 7.1:** The Effect of Reducing Transmitter Power (Noise at $-30$ dBq)

![Figure 7.2](image2.png)

**Figure 7.2:** The Effect of Adding AMC (Noise at $-30$ dBq)

As expected, the listeners varied greatly in their tolerance. However, it is clear from Figures 7.1 and 7.2 that reducing the transmitter power is more damaging than increasing the AMC by the same amount. For 6 dB AMC/reduction in transmitter power, the average difference in impairment score was 0.5 — in agreement with the results of the previous section.

The complete set of averages is plotted overleaf. The uncertainty was estimated by calculating the standard deviation of the scores (about 0.5 of an impairment point) and dividing by the square root of the number of listeners (15). There is a clear impairment trend as the transmitter power is reduced. In contrast, within experimental uncertainty, AMC appears to be nearly harmless.

To calculate the equivalent loss of transmitter power, take the slope of the ‘Tx Attenuation’ curve as 1 impairment unit per 10 dB. If AMC at 6 dB (arguably) reduces the sound quality by 0.1 impairment point, the equivalent loss of transmitter power is 1 dB.
Figure 7.3: Average Impairments (Noise at −30 dBq)

In the real world, some listeners would experience higher noise levels, because of poor receiver design or local reception conditions. AMC could then increase the impairment through noise pumping. To find out, the noise level was increased by 10 dB to −20 dBq, at which point many listeners would find it annoying. The results are plotted below:

Figure 7.4: The Effect of Reducing Transmitter Power (Noise at −20 dBq)

Figure 7.5: The Effect of Adding AMC (Noise at −20 dBq)
The scatter between the individual results is even greater than before, but once again averaging comes to the rescue, as the ‘Average Impairments’ plots show:

![Impairment Score vs. dB graph]

Figure 7.6: Average Impairments (Noise at –20 dBq)

In this case, the equivalent reduction in transmitter power is about 3 dB for AMC at 6 dB. It was noted during the tests that the noise-pumping rapidly became more objectionable as the basic noise level was increased. This is presumably the noise-masking phenomenon in reverse: at some point, the noise is such as to mask the programme material rather than the other way about.

8. **Power Consumption Measurements on Service Transmitters**

An initial trial was conducted at Arqiva’s Washford transmitter site, to find out whether the actual power savings agreed with those expected from the laboratory measurements. This choice was simply a matter of convenience, as the transmission equipment is notionally identical at all sites under consideration. One of the two BBC Radio Wales 50 kW transmitters (operating on 882 kHz) was switched to the station test-load, and the power consumption measured with AMC settings of 0, 3 and 6 dB. Changing the setting was easily accomplished by moving a link in the AM6/34A compander, as illustrated in Appendix 3. The original attack time of 0.3 ms was retained, since audio quality was not being considered at this stage. To make the measurement, a power consumption analyser was connected to the 3-phase 415 V input to the transmitter.

To start with, the power consumption was measured with the transmitter delivering 50 kW of unmodulated carrier, so that the efficiency could be compared with that originally specified by the manufacturer. The aim was to ensure that the transmitter was in good working order and appropriately aligned. Three further measurements were then made with modulation present and AMC settings of 0, 3 and 6 dB, with the duration of each test being 60 minutes. The modulation was typical BBC Radio 5 Live programme material of news and current affairs, and was played through the standard audio processor. It was identical for each test. The results were as follows:

- **Unmodulated Carrier**
  The manufacturer quotes the transmitter efficiency as 61% for a 50 kW unmodulated carrier, equivalent to 81 kW power consumption. The measured consumption was 90 kW — an efficiency of 55%. Although slightly less than the manufacturer’s figure, it is still very good for a transmitter nearing 40 years in service, and confirms the accuracy of the alignment.

- **Modulated Carrier, 0 dB AMC**
  The manufacturers give the transmitter efficiency as 57% for a 50 kW carrier with 45% average modulation depth — an average power consumption of 97 kW. The measured average consumption was 105 kW, or an efficiency of 52%. In percentage terms, this result compares well with that for the unmodulated carrier.
• **Modulated Carrier, 3 and 6 dB AMC**

With 3 and 6 dB AMC, the tests showed the average power consumption to be 72 and 60 kW respectively (again with an average modulation depth of 45%). Hence moving from 3 to 6 dB promises an average power saving of 12 kW, or 17%. According to the earlier laboratory measurements described in Section 4, the expected savings are about 21 kW. Although the ‘real’ saving appears slightly disappointing, it is not surprising: the calculations from the laboratory results assumed an ‘ideal’ system without overheads for cooling, filaments, bias supplies, low and medium power stages and the control system. Also, transmitter alignment is traditionally carried out at the full 50 kW, and could be sub-optimum at lower powers. Even so, a 12 kW saving is well worthwhile.

A further trial was carried out at Droitwich, where three Doherty transmitters of the same type as used at Washford provide a combined output of 150 kW. The power consumption of each transmitter was logged at 30-minute intervals, and the results summed over the duration of the tests to give the total consumption. These tests took place over identical periods of 28 days before and after the change in AMC — the transmitters were already operating with 3 dB AMC. Table 8.1 below summarises the results:

<table>
<thead>
<tr>
<th>Total Power Consumption in kWh</th>
<th>Power Saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 dB AMC (Before)</td>
<td>6 dB AMC (After)</td>
</tr>
<tr>
<td>157,705</td>
<td>137,865</td>
</tr>
</tbody>
</table>

**Table 8.1:** Results of Power Consumption Measurements at Droitwich

It was not practicable to measure the consumption, and hence the efficiency, without AMC, due to time constraints in the AMC upgrade procedure to the in-service transmitters and so a direct comparison cannot be made with the Washford results.

The power saving in moving from 3 to 6 dB AMC is rather less than the 17% Washford figure. Possible reasons for this are as follows:

- Although alignment of the transmitters is carried out in accordance with formal procedures, there will always be slight variations.
- A small uncertainty in the measurement of output power can make an appreciable difference to the apparent efficiency.
- There will be slight variations in the condition of the equipment — the age of the valves, for instance.
- At Droitwich, the measurement period was much longer than at Washford, and was conducted using three transmitters rather than one. The longer measurement period included a greater variety of programme material, resulting in a different average modulation depth.

9. **Field-Trials within the Washford and Droitwich Service Areas**

Field-trials were carried out within the areas served by the Washford and Droitwich transmitters, with the hope of confirming the laboratory findings and subsequent service area predictions. Both field-strengths and received audio quality were to be assessed. The first trials were carried out using the Washford transmitter — the more straightforward case, since co-channel interference is not a problem for this service in the south and east of England. Once the Washford trials had been completed, measurements were made using the Droitwich transmitter. Here there was significant co-channel interference from a number of other sites operating on 693 kHz, and the results were not expected to be so clear-cut.

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6 This figure is obtained by noting that the move from 3 dB to 6 dB AMC saves 20% power, and that 100% corresponds to 105 actual kilowatts.
The coverage maps for the two transmitters are shown below. The transmitter itself is indicated by a black cross, and the outer limit of the red shading corresponds to 60 dB$_{µV/m}$ — the edge of the service area as defined by the BBC and Arqiva. According to the laboratory work, introducing 6 dB AMC reduces the effective transmitter power by 1 dB. The predicted edge of the service area then corresponds to outer limit of the green shading. With 3 dB AMC, there is no effective reduction in transmitter power, and there is no need for separate diagrams.

**Figures 9.1 and 9.2:** Predicted Service Areas of the Washford (*left*) and Droitwich (*right*) Transmitters

Also shown on the coverage maps are the sites where the measurements were made. These are the blue dots along ‘radials’ from the transmitters. The radials were chosen so that the ground conductivity along them remained as constant as possible — the conductivity has an important effect on the propagation of the radio signal, and hence the consistency of the measurements. Also in the interests of consistency, reflective metallic objects and local sources of electrical noise were avoided. Generally, that meant choosing measurement locations in rural areas.

The two test receivers used for the measurements are shown below. On the left is a high-grade calibrated measurement receiver giving a direct read-out of field-strength, and on the right is a domestic portable radio. Only the portable radio was used for assessment of the audio quality.

**Figure 9.3:** The Two Receivers Used for the Field-Tests
Plots of field-strength and audio quality are shown below. In both cases, the horizontal axis corresponds to the measured value before the change from 3 to 6 dB AMC, and the vertical axis to the value after the change. If the values remain the same, as would ideally be the case, then they would fall on a straight line passing through the origin and having a gradient of unity. The audio quality was assessed according to the standard ITU-R 5-point scale, as for the earlier laboratory tests.

Figure 9.4: The Combined Field-Strength Measurements

Figure 9.5: The Combined Audio Quality Assessments

The general conclusion is that the increase in AMC has made no perceptible difference to either the measured field strength or the audio quality. The mean change in field-strength is less than 1 dB, which is within the measurement uncertainty. Similarly, audio quality remains unaffected, with a mean difference of less than 0.05 impairment point. At no time was noise-pumping noticeable.

7 The 5-point impairment scale only makes use of whole numbers, with the result that many of the assessments would have the same values. The Audio Quality plot would be misleading, since it would give no idea of the relative numbers of assessments with a particular grade. For that reason, some scatter has been deliberately added to the results. The deviation from the nearest whole number has no other significance.
10. Conclusion
This report has described work carried out jointly by the BBC and Arqiva to decide whether an increase in companding at MF sites can be achieved without a significant reduction in audio quality. If the carrier compression could be changed from 3 dB to 6 dB, a combination of laboratory work and live field-trials suggests that a reduction in electricity costs of about £86k per annum should be possible for the ten Radio 5 transmitters. Including the eight transmitters for Radios Scotland, Wales and Ulster would reduce costs by around £155k per annum.

Initial measurements made on the Washford and Droitwich transmitters have confirmed that the increase in compression achieves worthwhile savings in the real world. These savings are slightly less than indicated by the laboratory tests. Likely causes include variations in the average modulation level and the constant power consumed by the transmitter ancillary equipment. However, these are early days, and a change in transmitter alignment procedure could go part way to yielding results closer to the theoretical predictions.

Listening tests show that distortion artefacts caused by the existing companding process increase markedly when the carrier compression is set to 6 dB. The artefacts are partly non-linear in nature, and partly arise because the receiver AGC cannot follow the changes in carrier level. Both mechanisms can be overcome by an increase in attack time from the present 0.3 ms: 20 ms is adequate to remove the non-linearity, but around 50 ms is needed if the AGC is to absorb most of the carrier level changes. However, this second source of artefacts is aurally much less disturbing. With 6 dB compression and the longer attack time, the sound quality is appreciably better than it was originally with 3 dB compression.

In the real world, the wanted signal will be accompanied by noise. Increasing the compression inevitably increases pumping of this noise, but the tests show the effect is not audible for compression up to 6 dB and ‘moderate’ amounts of noise. More specifically, with an audio noise level of –30 dBq, corresponding to edge-of-service-area, AMC of 6 dB is equivalent to a reduction in transmitter power of about 1 dB. With the noise increased to an ‘annoying’ –20 dBq, the equivalent reduction is about 3 dB. However, such a degradation should only be experienced well outside the service area.

The work has also shown that there is no practical advantage in using an audio delay line to remove overshoots at the output of the transmitter. The presence of overshoots is beneficial to the overall transparency of the system, and has a negligible effect on the power consumption.

Thorough field-tests in the service areas of the Washford and Droitwich transmitters have confirmed the findings of the laboratory work. No adverse effects resulting from the increase in AMC have been seen.

11. Acknowledgements
The authors would like to thank the following especially for their contributions to the project:

- Kevin Thorley, for carrying out the transmitter modifications and measurements, and for providing general advice on transmission matters.
- Mary Smith and Phil Brown, for advice on spectrum planning matters.
- Steve Gwilliam for his detailed knowledge and guidance regarding the Doherty transmitters, and Michael Lever for his assistance in preparing for the field trials.
- Tim Cockram, for his detailed input and co-ordination throughout the project.
- Andy Ball, for planning and carrying out the copious field-measurements.
- Chris Jenkins, for designing the printed boards and boxes for the AMC Simulator and AMC Comparison Units that were vital to the laboratory investigation.
- Karen Kingston-Lee, for breadboarding the electronic items for the investigation.

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8 The transmitters are currently optimised for operation at 50 kW. It could be beneficial to align them at 25 kW — a more typical power level when AMC is in use.
12. References


13. Glossary of Terms
AGC Automatic gain control.
AM(C) Amplitude modulation (companding).

dBq The audio level in dB, measured with a quasi-peak detector and referenced to 0.775 V RMS (1mW into 600 Ω). In the context of this report, the reference is the audio level corresponding to 100% AM.

dBµV/m 0 dBµV/m corresponds to an electric field-strength of 1 µV/m (and 60 dBµV/m to 1 mV/m — the edge of the service area, as defined by the BBC and Arqiva).

DC Direct current.
RF Radio frequency.
Appendix 1: The Audio Samples Used for Assessing the Effects of Overshoots

Twenty samples of programme material were provided by Radio 5 to assist with the AMC investigations. Ten of these were ‘raw’, with uncontrolled levels, whilst the remaining 10 were the same samples subjected to audio processing. The processing normally takes place at the transmitting station, to avoid possible problems caused by group delay errors in the distribution chain. However, to obtain these samples, a processor was set up in the Radio 5 studios to mimic the processing at the transmitting station. The studio staff confirmed that the resulting sound quality was as expected.

The slightly abbreviated file-names are listed below, together with their associated durations, colour-coding and brief descriptions. Note that any comments about the programme level apply to the ‘raw’, non-processed files, before audio compression takes place.

<table>
<thead>
<tr>
<th>File-Name</th>
<th>Duration (min, sec)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jerusalem orchestra</td>
<td>3.10</td>
<td>Commentary for first and last 25 seconds, with a rendition of ‘Jerusalem’ for soprano and string quartet for the remainder of the time. The general modulation level is very low as a result of a brief burst of applause after the singing.</td>
</tr>
<tr>
<td>commentary with FX</td>
<td>7.00</td>
<td>A post-mortem of a football match with prominent angry crowd noise in the background. The first 25 seconds are a commentary on the match itself. The level before audio processing is fairly constant at around –6 dB.</td>
</tr>
<tr>
<td>30th May sport clip</td>
<td>6.36</td>
<td>A football commentary complete with typical background noise; fairly constant level at around –6 dB. Similar to previous sample!</td>
</tr>
<tr>
<td>NEW fighting talk</td>
<td>3.35</td>
<td>A discussion on boxing together with some pop music, jingles and sound effects.</td>
</tr>
<tr>
<td>NEW opener</td>
<td>2.20</td>
<td>A phone-in on politics over a poor-quality phone line (with gaps that not even the processor could remove). Followed by the usual trailers and jingles before the hour, then the news bulletin itself.</td>
</tr>
<tr>
<td>NEW trail and sport opener</td>
<td>2.23</td>
<td>The content is adequately described by the file name! The programme break includes a jingle. Fairly constant level at around –6 dB.</td>
</tr>
<tr>
<td>New travel, bed quiet</td>
<td>3.31</td>
<td>Much the same as above. The weather forecast takes up much of the middle section. The general programme level, especially for the weather, is quite low at about –14 dB.</td>
</tr>
<tr>
<td>news and sport bulletin</td>
<td>2.19</td>
<td>Again, the file-name is largely self-explanatory. The material is speech-only at a fairly low level, and contains appreciable gaps during the first half.</td>
</tr>
<tr>
<td>phone in with OB</td>
<td>2.54</td>
<td>A compere having a conversation with a couple of angry football fans over the phone. The first (and most angry) fan is at a fairly low level of –10 dB. The speech of the second fan is much less compressed (high peak-to-mean ratio).</td>
</tr>
<tr>
<td>poor quality presser</td>
<td>2.15</td>
<td>A resignation speech (following on from the above discussion). The speech sounds as if it was recorded in a bathroom. Because of a single splat, the normalised level is very low. There are large gaps as well. The commentary at the end is higher in level and with fewer gaps.</td>
</tr>
</tbody>
</table>

Table A1.1: Details of the Programme Files Used During Tests
Appendix 2: A Simulation of the AMC Process

A simulation of the companding process is straightforward to carry out with a tool such as an Excel spreadsheet, and is instructive when it comes to understanding how distortions can arise — and what one can do to minimise them. As an example for discussion, we shall take a 1 kHz tone with a step change in amplitude at 10 ms. The amplitude is 0.2 V before the change, and 1.0 V after. As shown in the plot below, the tone is superimposed upon a DC of 1 V. The DC sets the carrier level of the transmitter, and it follows that audio of amplitude 1 V gives rise to 100% AM.

![Input Waveform](image1)

**Figure A2.1:** The Input Waveform

The second plot shows the corresponding transmitter output, and the 100% AM is easy to see. Where longer time-periods are concerned, the presence of the RF carrier causes the plots to look excessively busy; hence only the modulation content, as per the first plot, will be shown in the following figures. The combination of the modulation and demodulation process is (ideally) transparent, and including the carrier does not add useful information.

![Transmitted Output](image2)

**Figure A2.2:** The Transmitter Output

Figure A2.3 overleaf shows the situation when 6 dB AMC is applied. The attack time and audio delay are both nominally 0.3 ms, as for the AM6/34 with the original settings. Note that the DC, which would have been 1 V in the absence of audio, is now only 0.5 V with full modulation.
The interesting thing is how the receiver treats the AMC-processed signal. If the AGC has a time-constant of 20 ms, the result is as below. Although the blue trace is labelled ‘Input Waveform’, it could equally as well be ‘Receiver Output in the Absence of AMC’. As there is no change of carrier level to exercise the AGC, the system is transparent.

![Figure A2.3: The Input Waveform after AMC Processing](image)

There are two things to note about the receiver output. First and most obvious is the slow attack: the sudden reduction in transmitter carrier power can only be compensated at the AGC’s leisure. Secondly, there is a transient associated with the change in carrier power. This is easy to see if the 1 kHz component is removed from the output, as in Figure A2.5 overleaf. The output DC falls abruptly by 50% from its initial 1 V, and then slowly recovers as the AGC adapts to the new carrier level. A practical receiver would have a DC block on its output, and the 1 V offset would disappear as a consequence. Depending on the time-constant of the block, the actual transient is likely to be shorter. The lowermost trace in Figure A2.5 shows the result of adding a block with a time-constant corresponding to 50 Hz.

It is obvious that the use of AMC with a short attack time is potentially a source of poor sound quality. The transients at the output of the receiver were clearly audible during the listening tests reported in Section 5, and are visible in the distortion residuals of Figure 5.2.
If the AMC attack time and audio delay are now increased to 6 ms — an option originally provided by the AM6/34A — the waveforms become as below:

**Figure A2.5:** The Receiver Output with AMC Present

**Figures A2.6 and A2.7:** The Transmitter and Receiver Outputs with 6 ms AMC Attack Time
The transient caused by the change in carrier level is now better controlled, but the 20 ms AGC time-constant still dominates the recovery time of the modulation. Note that the audio delay causes the modulation level to fall in advance of the change in carrier power.

If the attack time is increased to 40 ms, as suggested in this report, the slow recovery of the modulation level is largely eliminated. The plot below shows what happens if the audio delay is returned to 0.3 ms. Because the transmitter power is allowed to overshoot, the receiver output is correct at the start of the burst. As the overshoot dies away, the receiver output falls slightly because the AGC cannot quite keep up with the reducing carrier power. Once the transmitter power has stabilised (at 50 ms), the AGC eventually restores the receiver output to the correct level. These variations gave the characteristic ‘wobble’ that was noted during the listening tests.

\[\text{Figure A2.8: The Receiver Output with 40 ms AMC Attack Time}\]

Finally, it is worth looking in more detail at the transient caused by the sudden reduction in transmitter power, since this was the most disturbing impairment during listening tests. The plots below show the frequency spectra associated with attack times of 0.3, 6 and 40 ms.\(^9\) These were obtained using the Fourier analysis facility in Excel. The benefit of a long attack time is clear to see.

\[\text{Figure A2.9: Spectra of the Transients for Various AMC Attack Times}\]

\(^9\) For convenience, the audio delay was kept to the minimum of 0.3 ms for all three attack times. However, this parameter makes practically no difference to the transient.
Appendix 3: The AM6/34A Compander

The Compander Itself

The AM6/34A is quite a complicated piece of equipment, and includes such facilities as common-mode rejection on the audio input, monitoring circuitry, and provision for remote bypassing of the AMC. It is also ruggedised so that it can perform correctly in a hostile environment, where RF field-strengths are likely to be high. However, a simplified block diagram is helpful in understanding its essential elements:

![Simplified Block Diagram of the Compander](image)

**Figure A3.1:** Simplified Block Diagram of the Compander

The audio signal passes through a 6.5 kHz low-pass filter (A). This is needed because the AM6/34A implements the following time delay digitally, and higher frequency components would give rise to unpleasant aliasing effects in the analogue-to-digital conversion process.

The purpose of the side-chain B, C, D, H and G is to generate the AMC control voltage. B is a full-wave rectifier, and peak detector C holds the output at a level corresponding to the maximum amplitude of the audio signal. Time-constant CR determines the decay time of the detector, and hence that of the AMC system. D is a second-order low-pass filter, and its response determines the attack time of the AMC. It is this filter that this report recommends for modification.

Some further processing is needed to the output of the side-chain before it can be used as the AMC control voltage. At low audio levels, the main signal path E, I and J needs to possess maximum (unity) gain. The DC bias on adder G determines this. At higher levels, the control voltage needs to be subtracted from the DC bias, so as to reduce the gain. The potential divider H allows the maximum gain reduction to be set. In the AM6/34, a U-link allows a setting of between 0 and 6 dB in 0.5 dB steps. However, the AMC Simulator Unit used for the laboratory work offered a range of 0–10 dB in 1 dB steps.

If the output power of the transmitter is not to overshoot whilst gain reduction is taking place, the audio in the main signal path needs to be delayed by an amount corresponding to the attack time. In the AM6/34A, the delay is accomplished by a digital memory. The audio is converted into digital form and read into a random-access memory. It is then read out after the required interval and converted back to an analogue signal. Low-pass filter J removes any high-frequency conversion artefacts.

The multiplication process, shown in the diagram as taking place in I, is actually part of the digital-to-analogue conversion. It is neatly accomplished by varying the reference voltage of the converter. In the AMC Simulator, an analogue delay-line was used, and the multiplier was a separate (analogue) component. Only the short (0.3 ms) option was implemented.
Figure A3.2 below shows the AM6/34A Compander, with the hand-bag link for setting the amount of AMC highlighted. Also shown are the two additional capacitors for lengthening the attack time.

**Figure A3.2: The AM6/34A Companding Unit**

**Interface with the Transmitter**

Although Figure 3.1 shows only a single audio output from the Compander, there are in fact two: one each for the carrier valve and the peaking valve. Both outputs are DC-coupled, through high-power audio amplifiers within the transmitter, to the screen grids of the respective valves. The signal grids are fed with a constant RF drive, whilst the screen grids perform the modulation. The two audio outputs are processed by the Compander as explained overleaf. A much-simplified illustration of the Doherty transmitter is shown below:

**Figure A3.3: Simplified Diagram of the Transmitter, Showing the Two Audio Feeds**
The carrier valve audio feed includes the DC bias corresponding to the carrier level, as determined by the AMC. This is shown by the dashed line in Figure 3.3. If the AMC is inoperative (set to 0 dB), the bias remains constant. When the AMC is working, the bias and audio signal are reduced in sympathy, in accordance with the modulation depth. The positive and negative peaks of the audio are independently adjustable, hence allowing the linearity of the transmitter to be optimised.

The peaking valve output is also DC-coupled, but in this case the DC bias is held constant — it determines the working-point of the peaking valve. Negative-going modulation is clipped, since the peaking valve is only operative when positive-going modulation is present.