HOME CO-AX METAMORPHOSIS: FROM TV DISTRIBUTION TO CONTENT NETWORK

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Abstract

Signals being distributed through consumer premises often embark on an unpredictable journey through old cable with badly made extensions, low quality signal splitters and aging amplifiers. However, issues over cost, access to premises and liability hold operators back from upgrading home distributions to the same standard as their delivery networks.

This paper briefly recaps what a home network must provide from a home owner's perspective. It is assumed that the home owner has an existing co-ax distribution connected to a CATV network, and now wants to upgrade it to a full bi-directional home network to carry TV, data and voice between the ever growing mass of home infotainment equipment.

A range of typical distribution components are characterised for home network use to determine their performance in the reverse direction and frequencies outside of their intended band of operation. The impact of some non-ideal installation techniques is also examined.

Downstream signals to CPE (consumer premises equipment) are shown not to require any special attention since the requirements are the same for legacy purposes. Upstream signals require special attention and predictions are made to show how data rates of 60Mb/s can be achieved without modification to a badly installed home distribution system, although in-line filters are required to protect legacy receivers from upstream signals.

SETTING THE TARGET

With the adoption of multiple personal computers, distributed audio and video, gaming and a host of other networkable devices within the home it is no surprise that people want to link up all their devices over one network, and not have to run one co-ax to connect to the external network then another for their own equipment. It's important that the PC can connect to the TV and that the security system is connected to both. It's also important that their own local communications are kept private from the delivery network and neighbors. All too often systems are designed from an operator's perspective with scant regard for the end user needs.

The whole network installation needs to be painless for the home owner, so it's safe to assume that the equipment must be inexpensive, quick to install, need no specialist instrumentation, and leave the decorating intact.

SO YOU WANT TO USE YOUR ANALOG DISTRIBUTION AS A DIGITAL NETWORK?

In the eyes of the average DIYer, converting an existing co-ax network from analog to triple-play should be a piece of cake. If it worked for the old analog stuff then surely it must work for the digital stuff, after all it's the latest technology isn't it?

Ideal home networking technologies must be able to live up to this premise, which means they must be able to operate over any home network architecture where analog TV was successfully distributed with no modification to the infrastructure, even if the analog picture was noisy or distorted. Equally, it must also be able to reliably deliver return path signaling even though the network was never originally intended to be used for this purpose.

Of course, once the bi-directional digital communications are running over the co-ax, the home owner needs them to operate without causing interference to any legacy equipment that is not part of the digital network.

THE EVOLVING DISTRIBUTION

At some point in the co-ax distributions life it may have been able to handle bi-directional digital signaling, but as the systems grow organically over time, sometimes professionally and sometimes not, it is likely to contain problems that can scupper a seamless upgrade.

In the oldest installations the home co-ax system may have started out as a CATV feed into the living room and the master bedroom. Over time, the co-ax was split to feed other bedrooms, the study, the kitchen and maybe even the back yard. With a professional installation this would have been designed as a star system or 'branch and tap' configuration, but in many cases a splitter is simply inserted in the nearest available co-ax and, so long as the TV can get some kind of picture, then the job's done.

Figure 1 shows a substandard home-grown installation which largely matches the previous description. One of the splitters was accidentally installed the wrong way round which resulted in no picture in bedroom 3, and lower signals in bedrooms 1 and 2. To resolve this, a 20dB amplifier was installed at the star point. Finally, when the content network was upgraded for data, a cable modem was installed in the office.

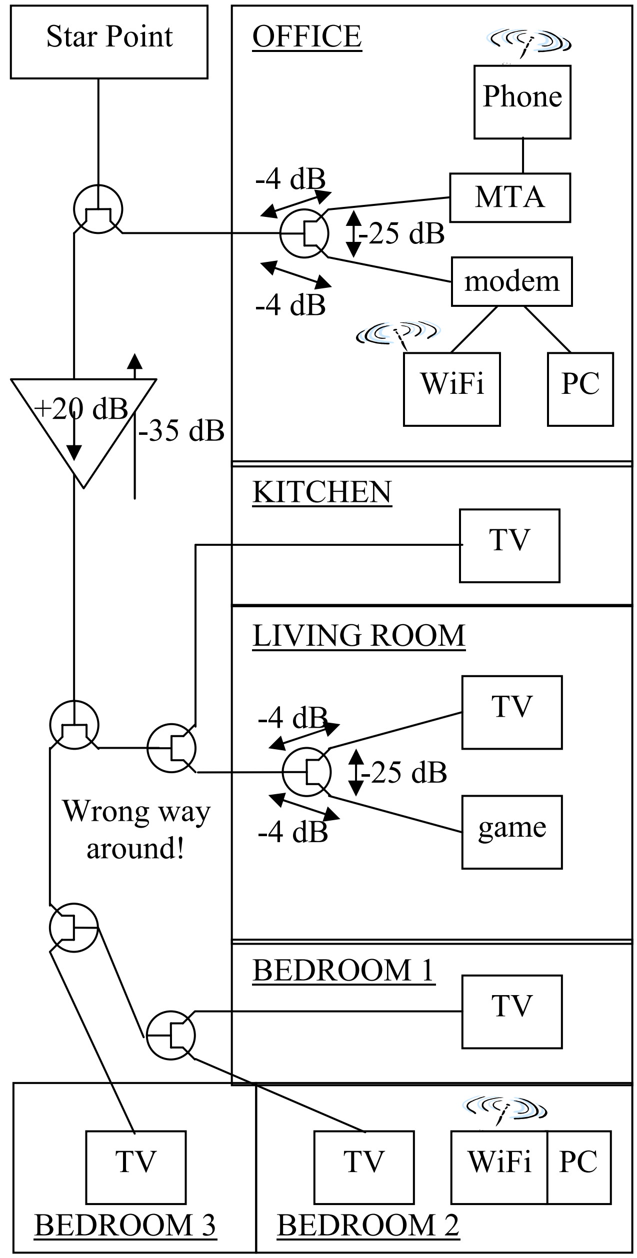

Figure 1. Reference legacy distribution

IT WORKS JUST FINE FOR ANALOG

At this time the network is carrying a full suite of analog, digital TV and data signals which consumes the entire spectrum from 5 to 870MHz.

From star to:	Signal gain
Office MTA	-7
Office CM	-7
Kitchen TV	6
Living room STB	9
Living room games	9
Bedroom 1 TV	5
Bedroom 2 TV	5
Bedroom 3 TV	-13

Figure 2. Signal gain between star point and all outlets

Figure 2 shows the averaged signal gain at each outlet for every path in the distribution in the traditional downstream 54 to 870 MHz band. The distribution is adequate for distributing signals from the star point with all outlets levels within 14dB of each other, apart from bedroom 3 with the splitter installation fault which results in a grainy but acceptable picture.

DISTRIBUTION BECOMES NETWORK

The biggest step change in converting the distribution is the ability to send signals in other directions. This means that new high-loss paths are created across some splitter outputs and in the reverse direction across amplifiers.

UNDERSTANDING THE NETWORK COMPONENTS

Co-ax

The most common cable choices over recent years are CT100 and CF100. The impedance is matched for 75 ohms and the attenuation is 10dB per 100 meters at 870MHz and 0.2dB at 5MHz. In general any other co-ax found in domestic installations will be of lower quality in terms of attenuation, frequency roll-off and impedance matches.

Following the notion that this co-ax has been good enough to pass legacy signals, then the cabling will be suitable for digital communications that use the same frequencies or lower.

Splitters

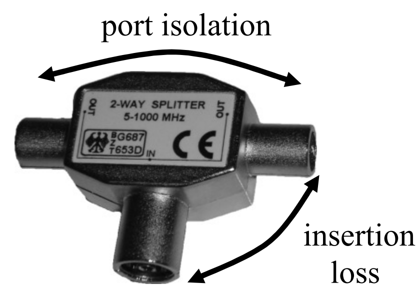

Figure 3. splitter sample #1

Almost all modern power splitters are the transformer type as these give minimum signal loss. When a signal is split, all the power is divided equally at each of the outputs and therefore the output signals are in theory 3dB lower than at the input. In practice there is some additional loss, typically between 0.5 and 1.5dB. The extent of this additional loss being indicative of the quality of the splitter.

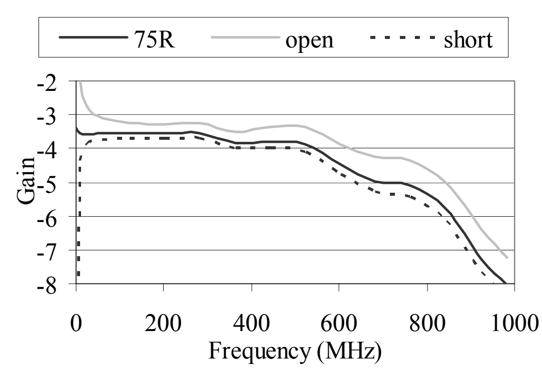

Figure 4. Transformer splitter insertion loss sample #1

The graph in figure 4 show that when the unused port is correctly terminated in 75 ohms the insertion loss is between 3.5 and 5.5dB up to 800MHz, but then rapidly increases to more than 8dB at 1GHz. Again, high frequency loss impacts on the potential of this unused spectrum. When the unused port has nothing connected to it, then the insertion loss is reduced by 0.5 to 1dB. Similarly a short increases the loss slightly. If an unterminated co-ax is connected to the unused port then these effects are reduced in proportion to the length of the co-ax.

High port isolation reduces the interference that is caused when two TV sets are tuned to the same channel. Figure 5 shows that when the input (common) port is correctly loaded in 75 ohms, then the port isolation is generally greater than 20dB. In practice it is unlikely that the common port will ever have a significant impedance mismatch at the common port as either an open or short here would result in no signals further down the distribution. However, the effects are shown here as they highlight a transformer-splitter's extreme sensitivity to common-port loading.

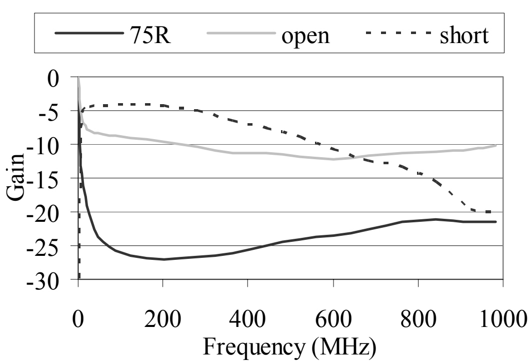

Figure 5. Transformer splitter port isolation sample #1

When using a distribution with splitters, consideration of the return path signaling must be taken. In this case a device transmitting across the output ports has the potential to saturate other receivers further up the distribution as a result of the low insertion loss in comparison to the port isolation.

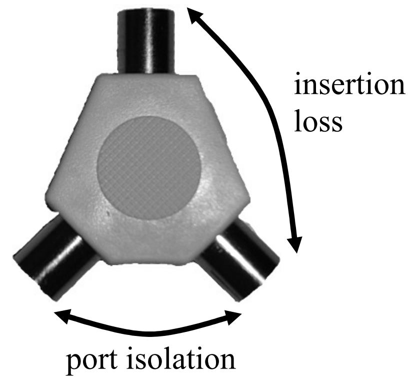

Figure 6. Splitter sample #2

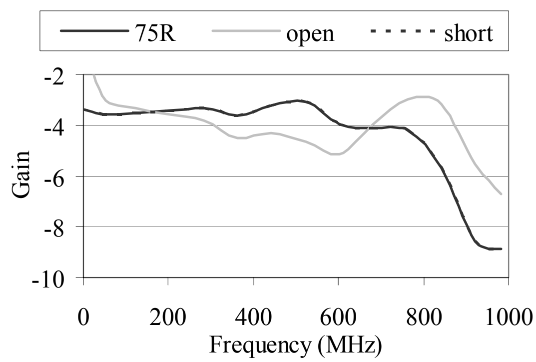

Figure 7. Transformer splitter insertion loss sample #2

There are a number of techniques used to construct a transformer-splitter. Figure 7 show that the insertion loss of a second type is much flatter than sample #1 to 800MHz with similar high frequency roll-off to 1GHz.

Trunk and Tap

This technique uses unequal splitters where the loss in each split along the trunk is very small, and each tap off the trunk has around 20dB of insertion loss. This system is rarely used in a single domestic installation and is more likely to be found in MDUs (multi dwelling units) or in the co-ax part of a HFC network.

Daisy-Chain

A simple, though incorrect way for an uninformed DIYer to install a new outlet is to run a spur from an existing outlet in a similar way a mains outlet might be wired.

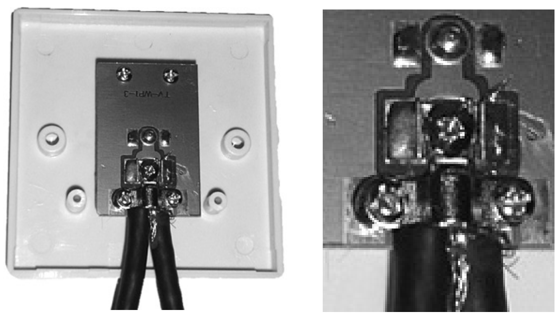

Figure 8. straight spur

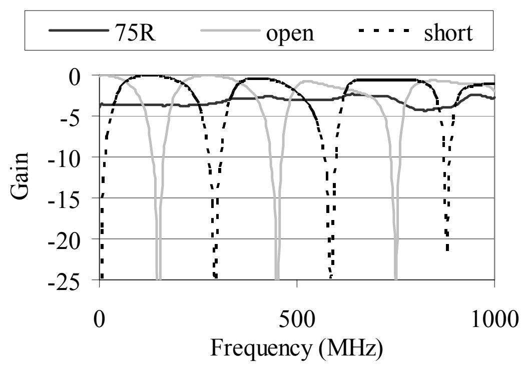

Figure 9. Daisy chain 17 cm spur

Figure 9 shows the frequency response between the incoming co-ax and the wall plate socket when there is a 17cm spur. This length is fairly typical when wall plates are mounted back-to-back either side of a wall. When the spur is loaded with 75 ohms, the insertion loss is approximately 3dB as theory predicts. Problems occur when the spur is not correctly loaded, the most typical instance being an open circuit. In this case nulls are presented in the frequency response. Figures 10 and 11 show that as the stub length increases then the effect is reduced.

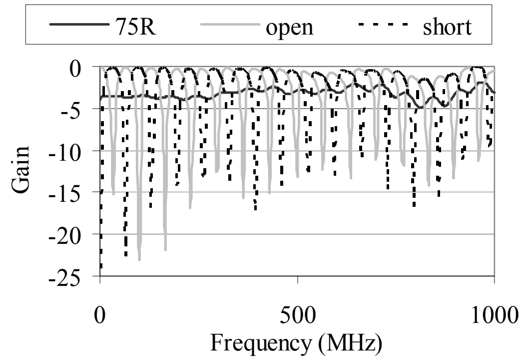

Figure 10. Daisy chain 300 cm

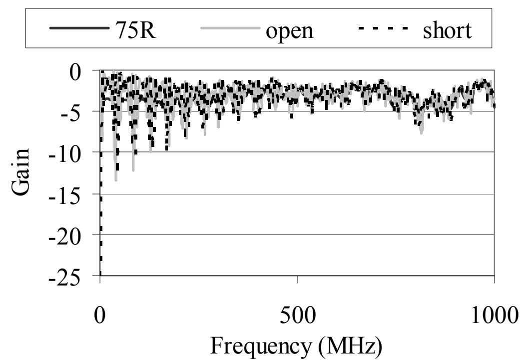

Figure 11. Daisy chain 900 cm

The major problems caused by unterminated spur outlets are loss of signal level, and channel tilt. Figure 12 is a snap-shot of the frequency response for two different spur lengths.

Signal loss can be more than 40dB within the nulls at certain frequencies which means that problems may have been masked in the past if legacy signals happened to avoid the nulls leading to the potential for misdiagnosis of issues when the distribution is switched to network.

Of equal importance is the gradient of the nulls which can result in channel tilt. The choice of communication system must take this into account either in its ability to avoid these frequencies, or simply to be robust enough to handle them.

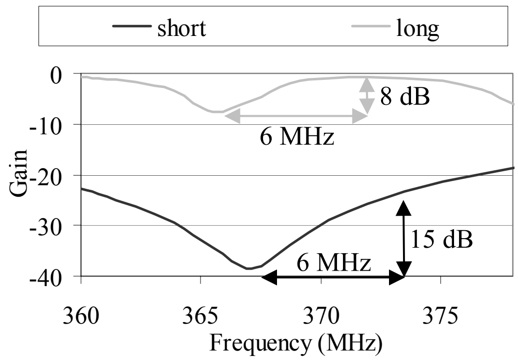

Figure 12. Unterminated cable lengths

One-way Amplifiers

Figure 13. variable gain amplifier

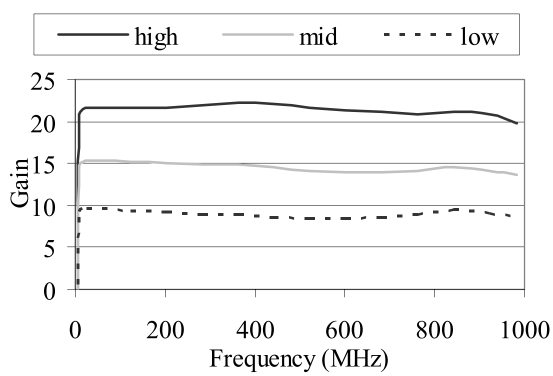

Figure 14. Amplifier Gain response

The sample characterized is a variable gain device with a range from 10 to 20dB. The gain response is flat within ±2dB from 5MHz to 1GHz as shown in figure 14.

The most important question is how a one-way amplifier handles upstream signals, that is, signals launched at high enough power to overcome the reverse isolation shown in figure 14.

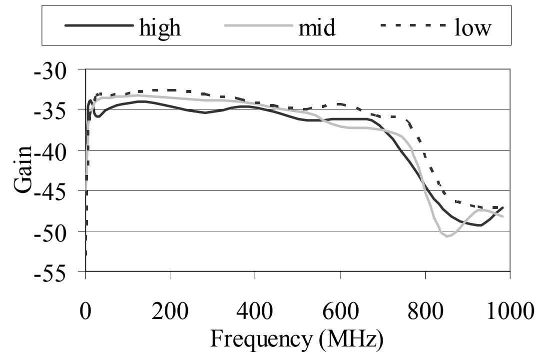

Figure 15. Amp reverse response

The main concern is signal distortion in the reverse direction. For this measurement the amplifier is intentionally characterized in reverse, so the input and output are interchanged. Figure 16 shows the third order intercept response measured at the output, i.e., the distortion on the signal once it has passed backwards through the amplifier. This particular amplifier uses current starvation to vary the gain which is why the best results are achieved at the highest gain setting. The intermodulation performance is also poor at the higher frequencies where signal levels have to be increased to overcome the amplifiers reverse isolation.

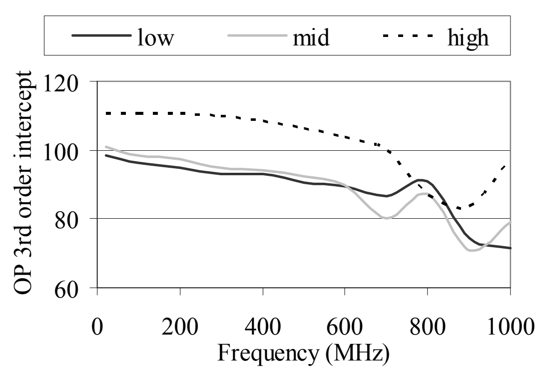

Figure 16. Amplifier IP3 response

UPSTREAM POSITIONING

There are three general frequency ranges to consider for upstream signaling, below 50MHz, 50 to 870MHz and above 870MHz.

Upstream in the 50-870MHz Band

Assuming that the downstream frequency range is fixed so that analog signals can pass to legacy receivers, table 2 (see next page) shows that the 50 to 870MHz band is not suitable for upstream because the high launch levels required will saturate downstream tuners with signal levels potentially being over 70dB greater than the wanted downstream. For example, to transmit from bedroom 2 to the office there is 80dB of loss to overcome. However, a downstream signal from the star point loses 8dB so for both signals to appear at the office at the same level, bedroom 2 must transmit 72dB higher than the downstream signals at the star point.

The gain between the star point and bedroom 2 is 2dB so the power of the upstream signal it is transmitting will be 70dB higher than the downstream signal which will cause its tuner to saturate, this is self interference. Similarly interference is caused to other client devices such as in bedroom 1 where the transmit signal intended for the office will be 72 – 1 – 26 = 45dB more than its downstream signal in bedroom 1.

Segregating the Signal Bands

Seperating the upstream and downstream into two bands allows the downstream tuners to be protected from the high power upstream signals using band filters or diplexers, therefore tuner saturation is avoided.

Tables 1 and 3 use the average characteristics of the distribution network operating in the 0 to 50MHz and 870MHz to 1GHz bands respectively. The overall difference in the network's performance in these two bands is that, at higher frequencies, there always greater signal loss to overcome. Signal loss impacts the carrier-to-noise ratio and thereby limits the efficiency of the modulation schemes available.

In addition to increased signal loss it has also been shown that when a one-way amplifier is present, the reverse intermodulation performance is also impaired at high frequencies. This limits the maximum transmit signal level which again affects the carrier-to-noise ratio thereby reducing the ability to use efficient modulation schemes.

HOW MUCH BANDWIDTH?

There are many different usage profiles to consider which can include internet usage, bulk file transfers between PCs, multi-room digital video recorders (DVRs) to name but a few. On top of this there are various usage profiles for all these applications. For the purpose of this paper, the model used to estimate the bandwidth budget internal to the home is to consider two 12Mb/s digital video files being played across the network at the same time, one of which can be at 4 x speed for trick modes giving a combined data rate requirement of 60Mb/s. This aggressive case is likely to cover most other cases.

Within the reference model, the restrictions imposed by incorrectly installed splitter 4, and distortion in the reverse direction across a one-way amplifier limits the choice of modulation efficiency to two bits per Hz. A 20 per cent provision for overhead reduces this to 1.7 bits per Hz data rate which requires 36MHz of spectrum. With the amplifier removed and the splitter installed correctly then a modulation efficiency of 3.4 bits per Hz can be used thereby reducing the sectrum required to 18MHz.

Low band		To								
		star	office MTA	office CM	Kitchen	Living TV	Living Games	Bed1	Bed2	Bed3
From	star	-	-7	-7	6	9	9	5	5	-13
	office MTA	-7	-	-25	-16	-20	-20	-20	-20	-38
	office CM	-7	-25	-	-16	-20	-20	-20	-20	-38
	Kitchen	-46	-71	-71	-	-29	-29	-36	-36	-54
	Living TV	-49	-75	-75	-29	-	-25	-40	-40	-58
	Living games	-49	-75	-75	-29	-25	-	-40	-40	-58
	Bed1	-50	-75	-75	-36	-40	-40	-	-25	-7
	Bed2	-50	-75	-75	-36	-40	-40	-25	-	-7
	Bed3	-68	-93	-93	-54	-58	-58	-29	-29	-

Table 1. Average signal gain for 0 to 50 MHz for all outlet routes

Mid band		To								
		star	office MTA	office CM	Kitchen	Living TV	Living Games	Bed1	Bed2	Bed3
From	star	-	-8	-8	2	6	6	2	1	-15
	office MTA	-8	-	-25	-19	-24	-24	-25	-25	-42
	office CM	-8	-25	-	-19	-24	-24	-25	-25	-42
	Kitchen	-49	-74	-74	-	-30	-30	-39	-39	-56
	Living TV	-53	-79	-79	-30	-	-25	-43	-43	-60
	Living games	-53	-79	-79	-30	-25	-	-43	-43	-60
	Bed1	-53	-80	-80	-39	-43	-43	-	-26	-10
	Bed2	-54	-80	-80	-39	-43	-43	-26	-	-9
	Bed3	-70	-97	-97	-56	-60	-60	-31	-30	-

Table 2. Average signal gain for 50 to 870 MHz for all outlet routes

High band		To								
		star	office MTA	office CM	Kitchen	Living TV	Living Games	Bed1	Bed2	Bed3
From	star	-	-12	-12	-5	1	1	-6	-7	-14
	office MTA	-12	-	-20	-20	-27	-27	-28	-28	-36
	office CM	-12	-20	-	-20	-27	-27	-28	-28	-36
	Kitchen	-65	-85	-85	-	-27	-27	-40	-40	-49
	Living TV	-69	-92	-92	-27	-	-20	-46	-46	-54
	Living games	-69	-92	-92	-27	-20	-	-46	-46	-54
	Bed1	-71	-93	-93	-40	-46	-46	-	-21	-13
	Bed2	-72	-93	-93	-40	-46	-46	-21	-	-12
	Bed3	-79	-101	-101	-49	-54	-54	-28	-27	-

Table 3. Average signal gain for 870 MHz to 1 GHz for all outlet routes

CONCLUSIONS

There are three major factors to be understood in order to provide an ideal solution that can use the home broadcast distribution networks as a bi-directional digital network. These factors are all regarding upstream as any downstream signals are assumed to work in line with legacy services.

Attenuation paths within the distribution mean that upstream and downstream channels must be separated into discrete bands of frequency so that receiver tuners can be protected by filters from becoming saturated by return path signals.

Attenuation within the distribution is highest at higher frequencies, therefore the 0 to 50MHz region is the best choice for the return path since this allows the use of more efficient modulation schemes.

Upstream signaling can be blasted the wrong way across one-way amplifiers but the levels are restricted by reverse intermodulation performance. This is made worse when a variable-gain amplifier is set to low gain but only becomes a significant when this event is in combination with another extraordinary case such as a splitter installed incorrectly, or an unterminated spur.