Decibels

You don't have to be involved very long in electronics, TV antenna installation, HiFi or professional audio before you come across the term "decibel", or its common contraction "dB" (pronounced "Dee-Bee"). Because of the often offhand way in which these terms are thrown around, it can be hard to work out what these terms actually mean, why they're being used, or whether the person using them even understands what they really mean!

This all actually started in the late 19th century, when engineers were building the first commercial telephone systems. They soon realized they needed some way to standardize performance measurements of their equipment - phone line loss, microphone efficiency and so on.

At first glance this seemed straightforward enough. Electrical engineers had already worked out standardized ways of measuring the electrical power and performance of lighting and motor systems; it would have seemed just a matter of scaling things down to work in milliwatts instead of Watts.

However they soon discovered it wasn't going to be as simple as that. The difference between 25 Watt, 50 Watt, and 100 Watt light bulbs is obvious enough: Compared to a 100W bulb, a 50W bulb will look about 50% as bright, a 25W bulb about 25% as bright and so on.

But when came to phone line audio, things turned out to be dramatically different.

1 milliwatt (1mW - about the headphone socket level of a modern portable music player) is typical of the highest audio power level expected by an old-fashioned telephone earpiece. When the early telephone engineers started doing actual measurements, they discovered a surprising thing: If the power level was reduced by 50% to (ie to 0.5 mW), the perceived difference in volume was hardly noticeable! Generally, while you can detect a 50% power decrease (or increase) on a steady tone easily enough if *you are listening for it*, with normal audio material, most people are unaware there has been a 50% power change. A drop of 75% (ie to 0.25mW) is more noticeable, but it is nothing like as dramatic as the perceived brightness difference between say, a 100W and a 25W light bulb!

So scientists began doing experiments to determine and document the way the average person's ear reacts to audio power changes. They tested large numbers of people, basically changing the audio levels and asking them to indicate when they thought the phone signals sounded "half (and twice) as loud". Crunching the numbers showed that most people interpreted an approximately 10:1 actual audio power level change as only a 2:1 *perceived* level change. So to most people, dropping from 1mW to 0.1mW is only perceived as being 50% quieter; a 100:1 power change is only interpreted as a change to 25%; 1,000:1 a change to 12% (2x2x2) and so on.

So, incredibly, dropping the power from 1 milliwatt down to 1 microwatt still produced a usable audio signal. They realized that this approximated a "logarithmic" response as follows:

A hundred-fold power change can be written as "10^2", but the perceived volume change for that is 2^2 = 2 x 2 or 4 times. A thousand-fold power change can be written as "10^3", but the perceived volume change is 2^3 = 2 x 2 x 2 or 8 times and so on. 10^1 is simply equal to 10, and 2^1 is simply 2, ie 10 times power change, which equates to "twice (or half) as loud."

As with normal logarithms, you can also have fractional values, for example a 50% power change (ie two times) can be expressed as 10$^{.3}$ since the antilog of 0.3 = 2 (Or close enough to 2)

The term they came up with to denote a *perceived* 50% volume change (ie a 10 times power change), was the "Bel" in honour of Alexander Graham Bell, the inventor of the telephone.

So, basically, a "one Bel" power level change makes the audio *perceived* as being 50% louder (or quieter).

The main advantage of using this system is that if you had a large number of different components making up the telephone system (eg the phones themselves, phone lines, switchboards, booster amplifiers etc), each part could be marked with its signal loss (or gain) in Bels by the manufacturer, and these can simply be added up to give an indication of the overall system performance.

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Suppose for example you have a telephone where the earpiece requires at least 10 microwatts to be considered useable by a person with average hearing. If your microphones put out about 1 milliwatt, that means your system can only tolerate a signal power loss of 100 times, that is 2 Bels. If you had a roll of phone wire that was marked "Loss: 0.3 Bels per km", then you could work out that your phone line could only be about 7 km long, because 0.3 x 7 = 2.1 Bels. If you needed a longer line (say 15km) then you would have to invest in heavier cable with lower loss, marked perhaps "Loss: 0.1 Bels per km".

Alternatively, you could consider using some sort of amplifier in the line. If your calculated line loss was 3 Bels, and your amplifier had a power gain of 10 times (+1 Bel), your total system loss could easily be calculated: +1 Bel - 3 Bel = -2 Bel, which would be satisfactory.

The main advantage of this is that it could all be worked out on paper in the planning stages.

But why "*Deci*bel"? The usual answer given is that the Bel is an inconveniently large unit, but the Decibel (one-tenth of a Bel) is hardly much of an improvement.

The real reason was more that in the late 19th century the world was educationally a very different place from today. Literacy and numeracy rates were far lower than they are now: For most people, 5 or 6 years of primary school education in a one-room schoolhouse was considered well-educated. In particular, most people only ever learned to calculate in fractions, decimal places were generally something people learned in High School!

There were no pocket calculators or computers in those days either, and since the average linesman was more noted for his horse riding and bushcraft skills than his "ciphering" abilities, keeping everything in simple, whole numbers that could be easily added together, was seen as the most practical way of getting the job done.

"Deci" is a somewhat archaic unit of the metric system, which originally had "Deci "(1/10) as well as "Centi" (1/100) and "Milli" (1/1000) prefixes. "DeciBel" is actually the only common usage of "deci" in the English-Speaking world; in modern usage, multiples of "milli" are preferred as there is less chance of confusing say 100mm and 10M than there is 10cm and 10M.

The decibel turned out to be a very practical way to compare two phone signals, because a power difference of 1.0dB corresponds closely to the smallest change in sound level that the human ear can detect — what psychologists and audiologists call a ""just noticeable difference' (JND). So although they could just have easily used "CentiBels" (one Bel = 100 Centibels), in practice nobody can hear a 1/100th of a Bel difference.

Mathematically the difference between two signals or signal levels is defined as:

$$dB = 10 \times \log(P1 \div P2)$$

where P1 and P2 are the two signal power levels.

So for example, if a 200 milliwatt signal is reduced to 35 milliwatts, the calculation is

dB =
$10 \times \log(200 \div 35)$ =
$10 \times (\log 5.72)$ =
10×0.76 =
7.6db

In modern usage, decimal places are common in decibel calculations, but as mentioned earlier they were not so commonly used by early engineers.

So the decibel was originally intended purely as an easily understandable means of comparing audio power levels, where the two levels may be measured in watts, milliwatts, microwatts or even kilowatts.

However, as electronics technologies advanced in the 20th century, engineers found it could be just as usefully applied to signal *voltage* changes.

Just to refresh your memory, in any resistive load, the power dissipated is proportional to the square of the applied voltage. So for example, connecting a 6 Volt battery across a 1.5Ω load will produce a dissipation of (6 x 6) ÷ 1.5 = 24 Watts.

This is explained by the fact that power dissipation is simply the product of the applied voltage and the resultant current flowing. The current flow is calculated by dividing the voltage by the resistance: 6V ÷ 1.5Ω = 4A, and if we then multiply 6 Volts by 4 Amps we get 24 Watts.
But remember that by increasing the voltage, we also cause the current to increase at the same rate,

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so if for example we doubled the voltage (from 6V to 12V), then the current would also double to 12 ÷ 1.5 = 8A. Multiplying 12V x 8A then gives 96W, four times the power at 12V.

Basically any change to the voltage produces a power change proportional to the square of that voltage change. So, as another example, if you go from 24V to 30V, the power increases by

(30 ÷ 24) x (30 ÷ 24) =
1.25 x 1.25 =
1.5625

Note that this doesn't tell you what the power dissipation actually *is*, that depends on the load resistance. But as long as the resistance is unchanged the power change will always be 1.5625 times.

So voltage changes can still be applied to decibels, as long as you keep in mind that the resulting dB figure relates to the *power change resulting from that voltage change*.

But it actually works out quite neatly, because if you remember, to multiply two numbers number using logarithms, you simply add the logarithms together. So, when you square a number, instead of multiplying it by itself, you simply add the log of the number to itself, or simply multiply the log by 2.

So for power changes you use:
db = 10 x log(P1÷P2)

While for voltage changes you use
db= 2 x 10 x log(V1÷V2) or just
db= 20 x log(V1÷V2)

Once again, while this may seem somewhat eccentric nowadays, remember that for most of the 20th century, there were no pocket calculators or personal computers, and so adding together a string of db figures was going to be a lot easier than multiplying the actual gain or loss values.

If you still needed to know the actual voltage coming out the end of a system, you had to calculate that by finding the anti-log of the final dB figure (usually by using a printed book of "Log Tables"), but that was still a lot quicker (and less error-prone) than doing a large string of multiplications!

So knowing two signal voltage levels, we can work out their difference in decibels — providing they are still associated with the same impedance level (eg 50Ω, 75Ω, 300Ω, 600Ω etc).

As you can see, though, the decibel wasn't intended to be a unit of absolute measurement like the metre, the kilogram, the ohm or the volt. It's basically just a unit of relative measurement; a way of comparing one signal level against another.

Nowadays decibels are used exactly like this in many different areas of electronics — measuring the frequency response of preamplifiers, amplifiers, filters, microphones and speakers, comparing the optical output levels of lasers or the microwave power output of transistors and ICs, and so on.

For example you may have noticed that the frequency response of things like amplifiers and filters is often measured between the points where the response is '3dB down'. This is simply because a drop of 3dB corresponds to halving the power level, which, while not the smallest change detectable, is just on the point where it is starting to become significant.

However this brings us to another fascinating aspect of human hearing, in that, while an *overall* 3dB change in level is not all that dramatic to the casual listener, a 3dB change to *part* of the signal spectrum definitely is. For example a bass or treble control that cuts or boosts signals below 300Hz or above 3kHz, has a much more dramatic effect on the perceived audio, than an overall 3dB change.

Some handy ""rules of thumb' to remember about decibels are that:

• A 20dB difference corresponds to a drop or gain of 10 times the voltage.

• A 10dB difference corresponds to a drop or gain of 10 times the power, or 3.162 times the voltage.

• A 3dB difference corresponds to a drop or gain of twice the power, or 1.414 (ie square root of 2) times the voltage.

• A 6dB difference corresponds to a drop or gain of twice the voltage, or four times the power.

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Although decibels are strictly speaking, purely a unit of relative measurement, you still often see them quoted in various fields as though they a unit of absolute measurement (similar to Volts, Amps etc). For example reporting a sound level of "100dB" around a noisy machine. (As seen on lawn mowers, power tools etc). But … 100dB relative to *what?*

Although it's rarely mentioned, what is actually meant by that is: "100dB relative to what is considered the quietest sound the average person is capable of hearing."

Which is a bit of a moving target to say the least, since people's hearing tends to vary enormously, depending of age, past exposure to loud sounds, earwax buildup, medical conditions etc!

However a sound pressure level of "0.2 nanoBars" is generally regarded as the lowest sound level detectable by the undamaged ear of a human in their mid-20s, at 1kHz, and so that is taken as the "0dB" point.

So, what exactly is a nanoBar? A "bar" is a measurement of pressure close enough to atmospheric pressure at sea level. As a measurement of sound intensity, it indicates the *average* pressure the sound source exerts on a diaphragm, such as a microphone diaphragm or an eardrum. A nanoBar is one-billionth of a bar, which is an indication of how sensitive the human ear actually is.

Of course air pressure is normally a static measurement, rather like DC voltage. With sound levels it's a calculation of the average displacement of the diaphragm ("in" and "out") much the way RMS AC voltages are calculated.

This is the sound level routinely referred to as "0dB", and when measurements are made of actual sound levels they're quoted in dB relative to this level. So the voices in a typical conversation might have a level of "65dB", while a loud Pub band might produce levels of around "120dB", meaning 65dB and 120dB above 0.2 Nanobars respectively.

Typical sound pressure levels measured according to this system are shown in table 1. Just remember that they're all relative to that reference level of 0.2 nanoBars at 1kHz, the nominal threshold of hearing.

Another example of quasi-absolute decibels is in the telephone, radio and recording industries, where

140dB	Large industrial siren
130dB	Threshold of feeling or pain
120dB	Close vicinity of aircraft engine
110dB	Amplified rock band performance
100dB	Close to loud car or truck horn
90dB	Human hearing starts to become at risk (approximate).
80dB	Symphony orchestra playing fortissimo; inside older train
70dB	Inside typical factory (heavy industry)
65dB	Typical office conversation
45dB	Inside typical home residence
30dB	Soft or background music
20dB	Quiet whisper
0dB	Threshold of audibility (nominal)

Table 1: Sound Pressure Levels in dB (relative to 0.2 nanoBar RMS at 1kHz

audio signals are often distributed in balanced circuits with a standardized impedance level of 600ohms.

In this case the reference signal level is a power level of 1mW (one milliwatt), which in a 600Ω circuit corresponds to a voltage level of 775mV RMS. This level is referred to as "0dBm" (m for "milliwatt"), so when you see audio signal levels given as "+10dBm" or "-30dBm", that means they're being quoted relative to 775mV RMS AC.

+10dBm" thus means 10dB above the 1mW level (ie 10mW), corresponding to a voltage of 2.448V across 600ohms. Similarly "-30dBm" means 30dB *below* the 1mW level, or 1µW (microwatt), corresponding to 24.5mV across 600ohms.

Yet another example of quasi-absolute decibels is in RF engineering, where signal and noise levels are often quoted as variously "dBu" or "dbuV". Actually the correct term is dBµ (or dBµV), "µ" being the Greek letter Mu, meaning "micro". In other words, decibels relative to a reference signal level of one microvolt. So a signal level of +20dBµV is actually 10uV, while a noise level of -10dBµV is actually 0.316uV (or 316 nanovolts).

Note that the maths is exactly the same, regardless of the impedance of the antenna system, whether it is 50Ω, 75Ω or 300Ω. However, one microvolt across 300Ω is only going to produce one quarter the power of one microvolt across 75Ω

Finally, you may occasionally see signal or attenuation levels quoted in numbers that look like decibel figures, but with the term "Nepers" (pronounced nay-pers) instead of "dB".

Nepers are an alternative logarithmic unit of relative measurement, like the decibel but based on Naperian or "natural" logarithms rather than common or "base 10" logarithms. Naperian logs use "e" or 2.71828 as their base, rather than 10. (Oddly enough though, it was a man called Euler who discovered that number – "Euler's number" – Napier was the discoverer of logarithms generally).

Nepers are mostly used when describing the performance of microwave equipment. Once again, this system was devised to simplify complex calculations in an era when calculating machines were rare or non-existent.

It's actually quite easy to convert relative measurements given in Nepers into decibels; just remember that one Neper = 8.686dB.

EXAMPLE OF USING DECIBELS TO SIMPLIFY ENGINEERING.

Here are some real-world examples of common engineering problem that can be most efficiently solved using dB techniques: Installing TV antenna systems. (These are is not intended to be a primer on installing antenna systems by any means; it's intended more to show how much easier the design process can be using decibels).

In the first example, suppose you want to install a TV antenna system in a two-story house, feeding three TV sets on the ground floor. Now, most "DIY-ers" these days simply buy what looks like it might be a suitable antenna, suitable cable, suitable splitter, and more or less hope for the best. And, thanks to the truly remarkable ability of modern TV sets to cope with enormous variations in signal strength, this approach works more often that you might expect!

However, if you're a professional antenna installer, time is money, and you generally can't afford to waste time selecting components by trial and error. Like a 19th century telephone installer, a competent antenna installer will plan the installation as far as possible ahead of time.

For best reception the antenna is normally mounted on the roof, and this is often not in most convenient spot, but where the best signal is, as determined by a portable signal strength meter.

In our hypothetical installation, it is determined that the total length of cable from the antenna to the

antenna socket furtherest from to the splitter will be 25 Metres.

TVs and set top boxes vary somewhat in their performance, but the usual minimum acceptable signal level is "50dBµV". Now, remember that means a 50dB increase over one Microvolt. 50dB equates to a power gain of 10^5 = 10,000 which in turn equates to a voltage gain equal to the square root of 10,000 = 316. So, you need an actual RF signal level of at least 316 x 1 microvolt, or 316 microvolts, for reliable reception.

Fortunately, you don't really need to worry overmuch about the actual voltage figure, since virtually all TV signal strength meters read directly in dBµV (often spoken as "Dee-Bee-You"). Where it does come in useful is the situation you need to consider the requirements of any TV signal amplifiers you might be using. For example, consider a signal level of 100dBµV. That equates to a power gain of 10^{10} = 10,000,000,000 over 1 microvolt. Taking the square root of that to get the voltage change, gives you 100,000 x 1 microvolt = 100,000 microvolts or 0.1 volts.

But that's the RMS voltage; an amplifier actually needs about 0.3Volts DC voltage swing to produce 0.1V RMS output. Most amplifiers can cope with that level without too much trouble, but once you start to climb above 100dBµV, small amplifiers start to run out of dynamic range. For example, going up to 120dBµV requires an available voltage swing of 3 Volts. While that may not sound like much, unlike audio amplifiers, VHF/UHF amplifiers don't have any negative feedback, so they are much more prone to non-linearity that causes cross-modulation. That's why most distribution amplifiers run off 12 to 17V DC.

Getting back to our example, for reliable reception we need at least 50dBµV at the antenna sockets. First of all, the signal is going to go through a 3-way splitter, so the signal going to the input is going to be divided 3 ways, so it will be approximately equal to the level of the input, divided by 3. The Log of 3 is about 0.477, which equates to a 4.77dB loss. Allowing for unavoidable splitter losses we can round this up to 5db. So, to get 50dBµV at the wall sockets will require 55dBµV at the input of the splitter, to make up the splitting loss.
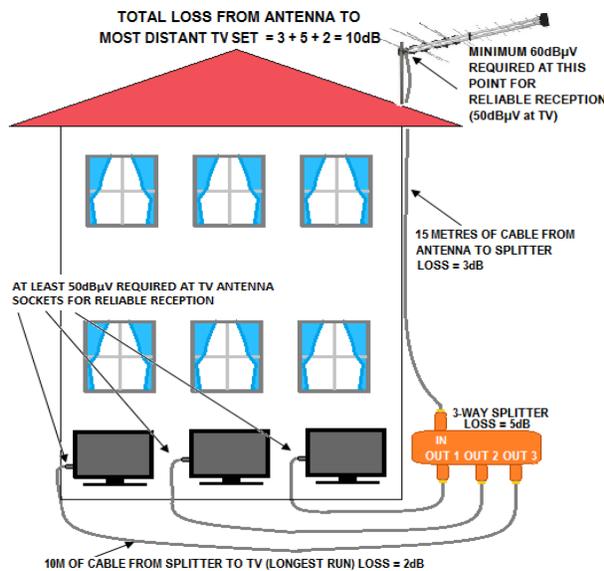
The next factor to consider is signal loss in the coaxial cable. A reasonable quality cable will typically have an attenuation of around 20dB per

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100 metres at the highest UHF frequencies used for TV. If you need a total of 25 Metres to get from the antenna to the most distant TV, that's going to mean an attenuation of about 5 dB. So, to get at least 50dBµV at the antenna sockets, you now need at least 55 + 5 = 60dBµV at the antenna end of the cable.

But now suppose you find that according to the signal meter, the mid-range antenna you thought might be suitable for the area is only delivering 54dBµV on the weakest signal (it's not unusual for the different channels to vary widely in their signal strength, so you always need to work with the lowest one). 54dBµV is 6dB less than the minimum recommended. Basically the installer needs to find a way to make up this 6dB shortfall.

The DIY-er approach might be to use a masthead amplifier. If this can supply at least 6dB gain, it will indeed cancel out the cable losses and get the signal strength up to the required level. While this will work, masthead amplifiers are not always reliable, plus you need to find a way to power it and so on.

A better approach would be to simply use a more efficient antenna. Generally antennas are also rated in dB, but in this case, it means power gain compared to a simple dipole (a dipole antenna is just two metal rods, more or less like an indoor antenna). Suppose the original antenna was rated as "6db"; if you can find one that's rated at 12dB or more, that would also make up the 6dB signal shortfall, without resorting to amplification.

TOTAL LOSS FROM ANTENNA TO MOST DISTANT TV SET = 3 + 5 + 2 = 10dB

MINIMUM 60dBµV REQUIRED AT THIS POINT FOR RELIABLE RECEPTION (50dBµV at TV)

15 METRES OF CABLE FROM ANTENNA TO SPLITTER LOSS = 3dB

AT LEAST 50dBµV REQUIRED AT TV ANTENNA SOCKETS FOR RELIABLE RECEPTION

3-WAY SPLITTER LOSS = 5dB
IN
OUT 1 OUT 2 OUT 3

10M OF CABLE FROM SPLITTER TO TV (LONGEST RUN) LOSS = 2dB

This is of course only a simple example. In the real world, an experienced installer would probably not need to plan ahead too much for a basic system like this. However, if the installation was in a large block of units, it would be a different story.

So here's a somewhat more elaborate example that better illustrates the value of using dB measurements.

In this case we have a six-story block of home units, each floor having 8 units, giving a total of 48 antenna connections.

Now clearly this is going to need an awful lot of signal. If you simply connected the distribution system to an ordinary antenna without amplification, it would be extremely unlikely you would get any reception at all.

It would also be impractical to simply use a single 48-way splitter (if you could even buy such a thing!) A more likely approach would be to have a six-way splitter to feed each floor, and then split each of those feeds eight ways.

Splitting the signal six ways would produce a signal loss of 10 x log(6) = 7.8dB, and allowing for splitter losses, about 8dB.

The subsequent 8-way splitters would add another loss of 10 x Log(8) = 9dB, giving a total loss of about 17dB. (If you reverse the calculation: $10^{1.7}$ = 50, which is close enough to 48).

As well as that, the signals may have to travel through as much as 50 Metres of cable to reach the outlying receivers on the ground floor. Assuming 20dB/100M cable, that means a maximum loss of 10dB in the cabling. So you would need a signal of about 10 + 17 = 27dB above 50dBµV to guarantee good reception in all units, that is, 77dBµV.

If your antenna delivers say 60dBµV, that's 10dB above 50dBµV already, so you will only need another 17dB gain to make up the difference.

Not many antennas are going to be able to deliver that signal level though, unless they are close to the transmitter. Instead, it would be normal practice to use a distribution amplifier. Amplifiers with 17dB gain are readily available, and with the relatively simple setup shown, a fairly inexpensive one would do the job.

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Below is a block diagram of such a system. This is a very conservative design, in that each unit on the floor has its own cable running from the splitter. That way, if a cable develops a fault, just that one unit will be affected. In theory at least, Unit F1 will receive a signal just 10 dB higher than Unit A8, which is well inside the normal acceptable signal strength range, and would generally be considered an extremely good result.
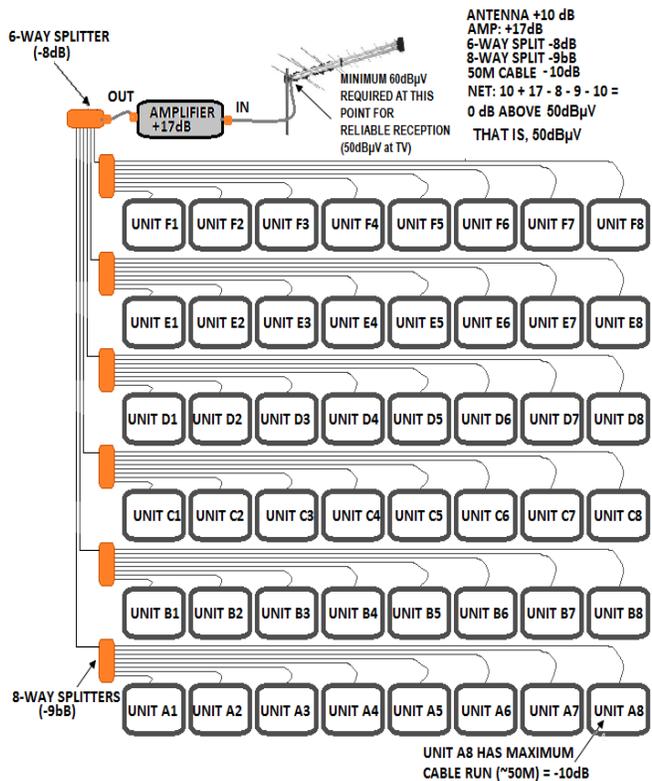
Unfortunately, while such a setup has much to recommend it, commercial installations are only rarely done this way. In the more usual situation, instead of each unit on a floor having its own feed from the splitter, a single cable is looped through all the units on the floor, and a small amount of signal is tapped off the cable for each of antenna socket.

While this is a perfectly acceptable way to distribute 240V AC power, for VHF and UHF signals it is fraught with problems, which is why apartment blocks, hotels and the like routinely have terrible TV reception.

It is not necessarily the fault of the installers either; often the cable is installed by the electricians doing the mains wiring, and it is left to the installer to try to make it work with the often cheap and nasty antenna cable permanently mounted in the walls!

This is an example where you really need to understand your dBs, but unfortunately, a lot of installers don't have the technical background, which again, is why there are so many botched installations.

So, here's the same block of units but this time using series-connected distribution cables with "Tee-Off's". A Tee-Off is a different type of splitter which has two terminals where the main signal is looped through, and a "Tap Off" which supplies an attenuated sample of the signal to the individual units' antenna sockets.
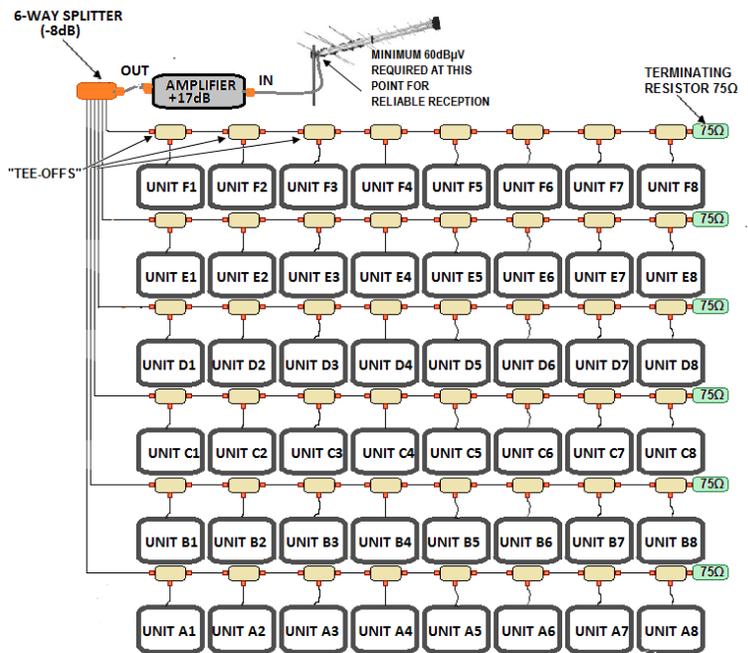
Tee-Offs come in various dB ratings and the concept is rather like distributing audio over a so-called "110V line". In that, each speaker has its own matching transformer, and by selecting the appropriate tapping on the transformer secondary, you can set the volume to the appropriate level for each location. (So for example, for a large assembly hall you would use a higher voltage tap than for a speaker mounted inside the toilets).

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"Inductive" Tee-Offs work more or less the same way, except the output levels are permanently built into them, and you have to select the most appropriate dB rating. For example, a "9dB" Tee-Off would deliver a signal to the antenna socket 9bB below the main feeder level.

So, if we had the same antenna/amplifier setup as before, divided through the same 6-way (8dB) splitter for each floor, 9dB Tee-Offs would give about the same signal level as the 8-way splitter used in the other installation?

Actually, that would only be correct in units A1, B1, C1 etc, that is, first tee-offs in the chain. After that it becomes more complicated. As mentioned earlier, a TV antenna distribution system is *not* like a 240V power installation. With 240V mains, if you use heavy enough cable, you can more or less add as many light bulbs as you like to the system, wherever you like, and the voltage across each bulb will still be close to 240V.

A TV coaxial cable acts more like it has a 75Ω resistor in series with it, so if you start tapping signal off the line the level will progressively drop.

Assume this time the antenna is delivering 62dBμV signal, and the amplifier supplies another 17dB gain, giving 79dBμV into the first splitter. That splitter takes out 8dB, leaving 71 dB at the start of each floor's cable run.

This is where it gets messy! You might imagine a 9dB Tee-Off will mean the Unit 1 gets 71-9 = 62dB above 1 μV, which is a good strong signal.

However you don't get something for nothing; that 62dBμV has to come from somewhere. In this case it has to be siphoned out of the distribution system. A 9dB Tee-Off will deliver about one-eighth of the main signal power to the wall socket, which means that the signal carried by the main cable must also be attenuated by one-eighth, which is the same as dividing it by 1.25. The log of 1.25 is very close to 1, so we can say that the main signal has been dropped by 1dB. You also have to allow a further 2dB loss for 10 Metres or so of cable and its extra "F" connectors, so you will really be tapping off a 68dBμV signal, not 71dBμV. So unit 1 gets 68 – 9 = 59dBμV, which is still a good signal.

For the next Tee-Off, you have to allow a further 3dB loss for the cable and signal feed which means you're now dropping 9dB from 65dBμV, and Unit 2 gets 56 dBμV, still OK. But you can see where this is going: Each stage of the chain knocks out another 3dB of signal. Unit 4 is the last one to get a satisfactory signal at exactly 50dBμV.

By the time you've done this eight times, the signal will be down 8 x 3 = 24dB! Since you're staring out with only 50dBμV + 21dB = 71dBμV, all the Unit "8's" will be getting only 71 -24 -9 = 38dBμV. Which might work, but only just, and with no room for error

Could you put in lower attenuation Tee-Offs? Yes, but then you will sucking a greater amount of signal out of each Tee-Off, which means the signal will disappear even faster.

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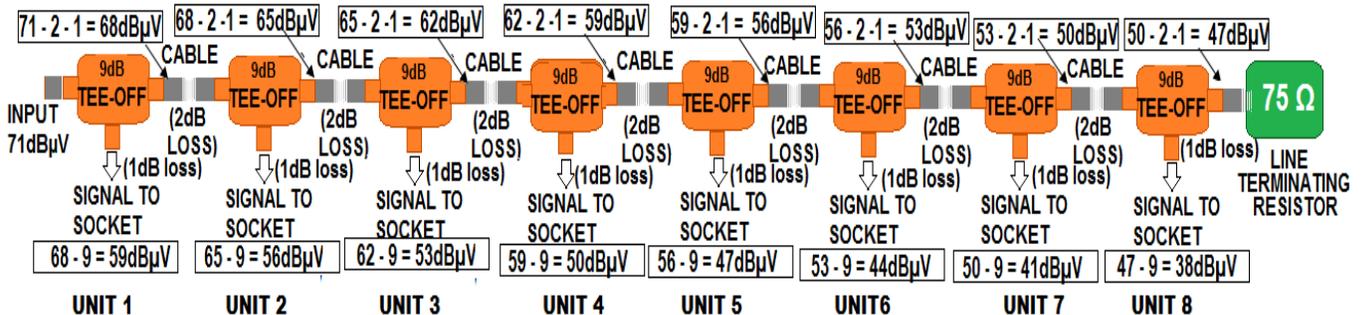
So how can we fix this? Well since unit 8 is 12dB below the satisfactory minimum signal level we could crank up the gain of the amplifier by 12dB. The input to each floors distribution cable would then be 83dB. Unit 8 would then get the minimum 50dBµV, but Unit 1 would then get 59 + 12 = 71dB at the wall socket, a trifle high but acceptable.

The real problem would occur if you tried to extend the system further. Suppose there were 16 outlets on each line instead of 8. That would mean a cumulative loss at the far end of 48dB. To get the required 50dBµV at unit 16 would mean adding another 24dB to the amplifier gain, making a grand total of 17 + 12 + 24 = 53dB. With a 62dBµV input signal that would mean it would be putting out 117dBµV *on the weakest channel,* and so if any of the other channels were significantly stronger, you would need an extremely well-designed (ie expensive) amplifier to avoid cross-modulation.

In any event, amplifiers with that level of gain are rarely used; it would be far cheaper to put in a separate 36dB amplifier on each floor.

The other problem would be that unit 1 would now be outputting 71 + 24 = 96dBµV, outside the maximum recommended range for reliable reception.

A common way to solve this problem to use Tee-Offs with a much higher attenuation factor, typically around 21-24dB, at the start of the line, and change to lower attenuation versions as you move towards the ends.

So if your first Tee-Off was a 24dB type, that would knock the 96dBµV down to 72dB, a much more acceptable figure. Additionally, a 24dB unit would be pulling a lot less than 1dB out of the feeder line, so you could assume the total loss to be only 2dB per Tee-Off. That means you could use up to ten more 24dB Tee-Offs before the socket signal started to drop down to around 50dBµV, but then you could start over, using lower attenuation Tee-Offs.

Really proficient installation engineers would "roll their own", making so-called "resistive" Tap-Offs to order, (see diagram next column) but that level of expertise is not commonly found these days. In this case the attenuation is produced by the voltage divider formed by the dropping resistor R1, and the 75Ω input impedance of the TV receiver's antenna socket.
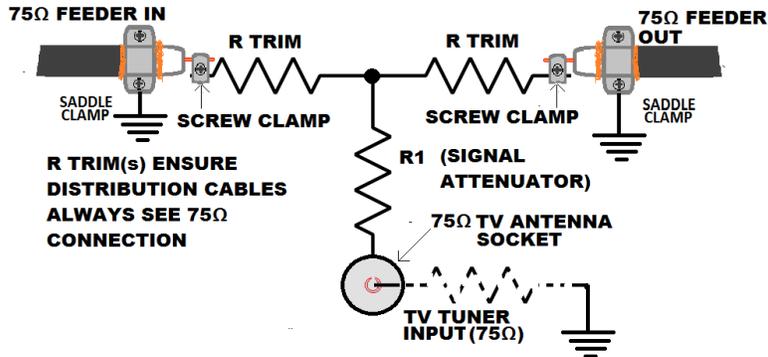
Here is a table of common values used. The "Trim" resistors are needed to minimize cumulative impedance errors in long cable runs. For example, putting a 1,000Ω resistor across a 75Ω tapping to produce a 23dB tap makes both feed cables see an impedance of about 70Ω; adding the 5.6Ω resistors restores it to the correct 75Ω. Generally the effect on the signal level can be ignored, unless it is a very large system.

R1 (Ω)	ATT (dB)	R TRIM (Ω)
3300	33	1.5
2700	31	2.2
2200	29	2.2
1800	27	2.7
1500	26	3.3
1200	24	4.7
1000	23	5.6
820	21	6.8
680	20	8.2
560	18	8.2
470	17	10
390	15	12
330	14	15
270	13	15
220	11	18

UNDERSTANDING DECIBELS

The above system using separate Tee-Offs for each unit is a reasonable approach, but unfortunately, most installers "cut out the middle man" so to speak, using Tee-Offs built into the wall socket. Many of these do not use "F" connectors, relying on cheap screws and "saddle clamps" to connect to the distribution cable.
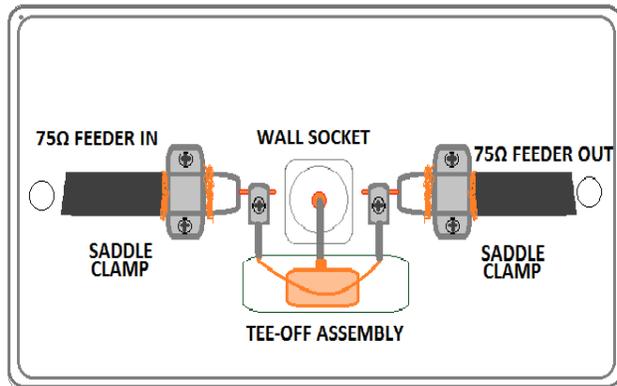
By far the biggest problem with this system is that if just one of the many Co-Ax connections is faulty, it completely ruins reception for the rest of the sockets in the line. Many apartment blocks erected in the 1970s also had rather cheap coaxial cable actually cemented into the walls, and suffered (and continue to suffer) terrible corrosion problems.

Installers and maintenance people have their work cut out for them trying to salvage something from that sort of situation; a good signal strength meter and a good knowledge of decibels can make the job at least manageable. However, no amount of planning and pre-calculation will help you if the infrastructure itself is faulty.

To round this off, we will add one further equation you might find useful: attenuation in dB of resistive dividers. On the next column is shown the conventional calculation for determining signal attenuation
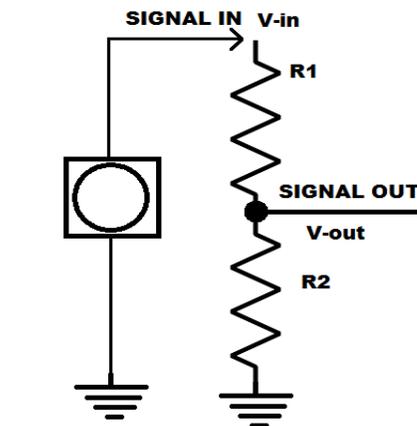
For example, if R1 was 22K and R2 10K, then the output level V-out would equal : V-in x 10,000 ÷ (22,000 + 10,000) (or V-in x 0.33).

Since this is a voltage change, the resultant power change is proportional to the square of the change so the decibel change is calculated as follows:

$$dB = -20 \times Log(1 + (R2 \div R1))$$

$$V\text{-out} = V\text{-in} \times R2 \div (R1 + R2)$$
$$\text{ATTENUATION FACTOR} = (R1 + R2) \div R2$$
$$\text{OR } 1 + (R1 \div R2)$$

Note that it will always be a "minus" figure because resistors only ever attenuate.

A FEW FINAL NOTES

1. Apart from the "Nepers" mentioned earlier, all dB calculations use logs to base 10. Most Scientific calculators allow you to switch between Naperian ("Natural") and Base-10 logs, but if you intend to write any sort of software incorporating logarithm calculations, you need to be aware that most programming languages either only work in Naperian logarithms, or default to them. To convert a Naperian-base logarithm to base-10, simply divide it by 2.303.

2. The calculator that comes with Windows has a "scientific" mode which is useful for these sorts of calculations. Simply select "Scientific" from the "view" menu.

4. It is not always understood that a decibel change anywhere "upstream" of a particular measurement point will produce the same change at every measurement point below that. So for example, if you put in a new antenna with 2dB more gain than the old one, *every* antenna point in the entire building will see the same 2dB change, regardless of how many stages of attenuation the signal has gone through.

3. Professional TV signal strength meters allow accurate signal strength measurements of individual channel frequencies over the entire VHF and UHF bands, typically from about 20dBµV to 130dBµV.

However, they are quite expensive to buy (typically $800 - $1,200).

Simpler units such as the Jaycar LT3332 shown below only give an average signal strength reading, and only over the range 50dBμV to 80dBμV, but, considering they cost somewhere between 3-5% of the price of a professional unit, they are still surprisingly effective for analyzing simple distribution setups, pointing your antenna in the correct direction, seeing if your antenna is working at all, and so on.

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